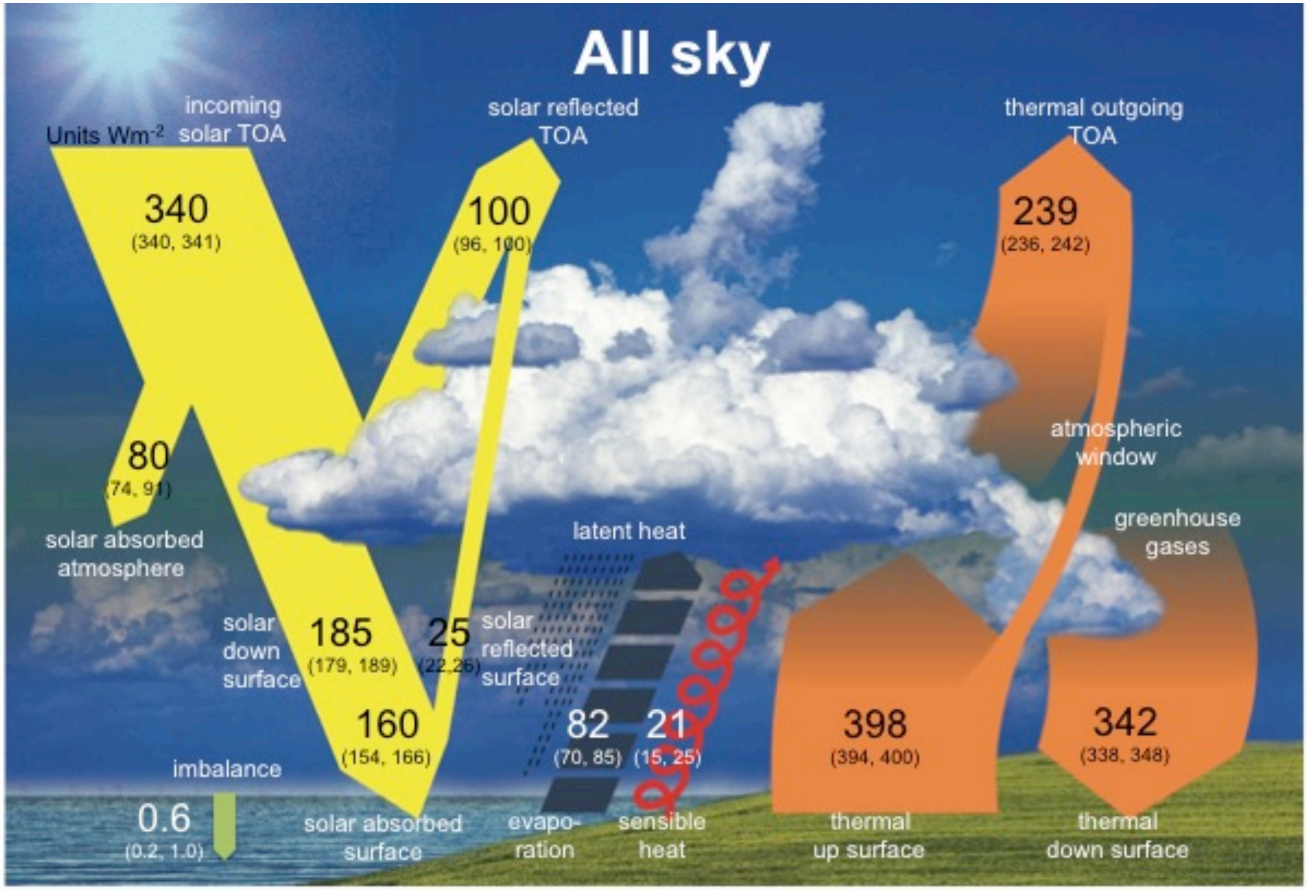
Use of BSRN data to estimate the Global Energy Balance and its changes

Martin Wild
ETH Zurich, Switzerland
wild@ethz.ch

Acknowlegements to Maria Hakuba, Doris Folini, Veronica Manara, Chuck Long, Arturo Sanchez Lorenzo, Matthias Schwarz, Yang Su

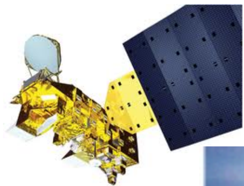
Earth Radiation Budget

Units Wm^{-2}



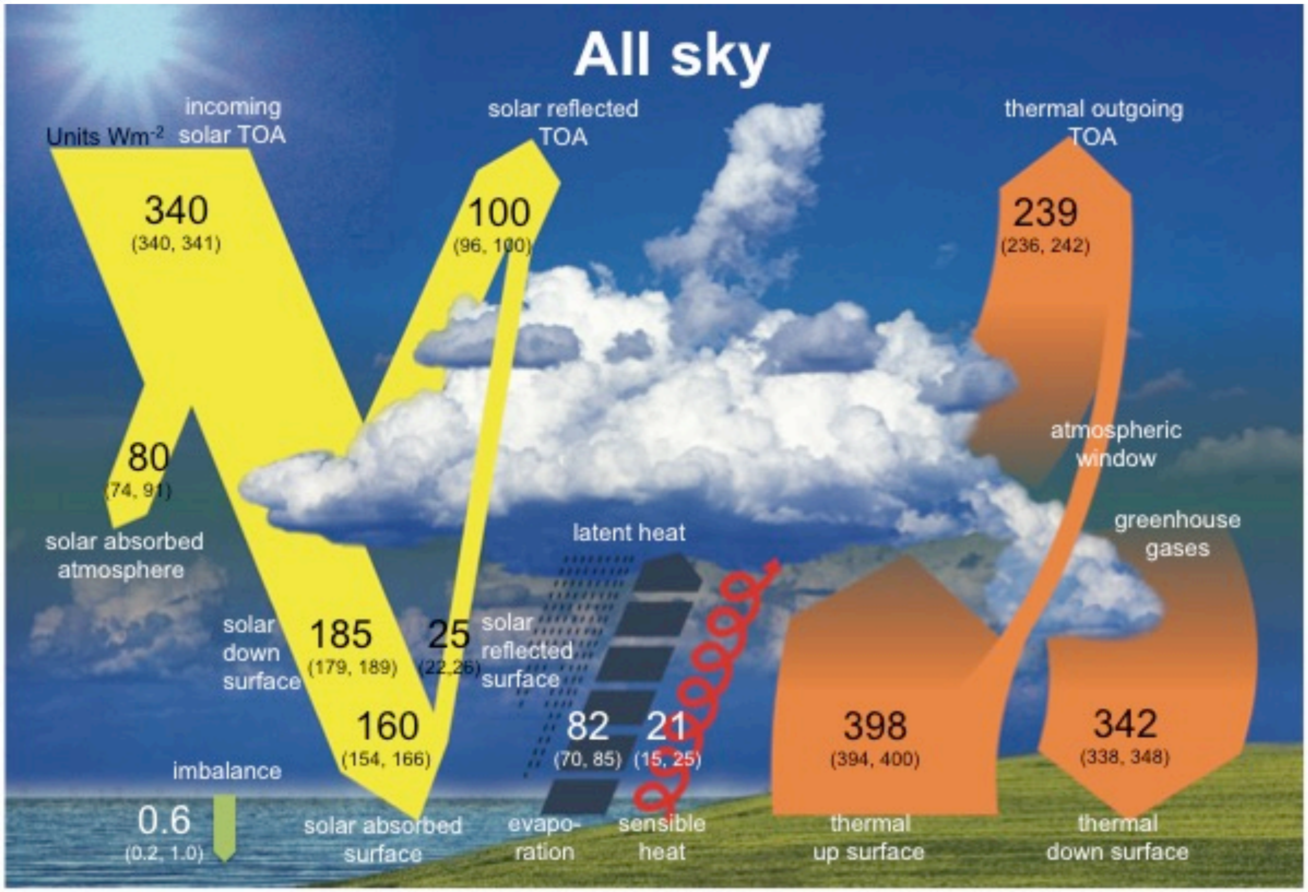
IPCC AR5 Fig. 2.11 / Wild et al. 2013, 2015 Climate Dynamics

Earth Radiation Budget



TOA fluxes from CERES satellite data

Units Wm^{-2}



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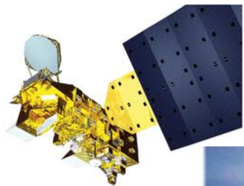

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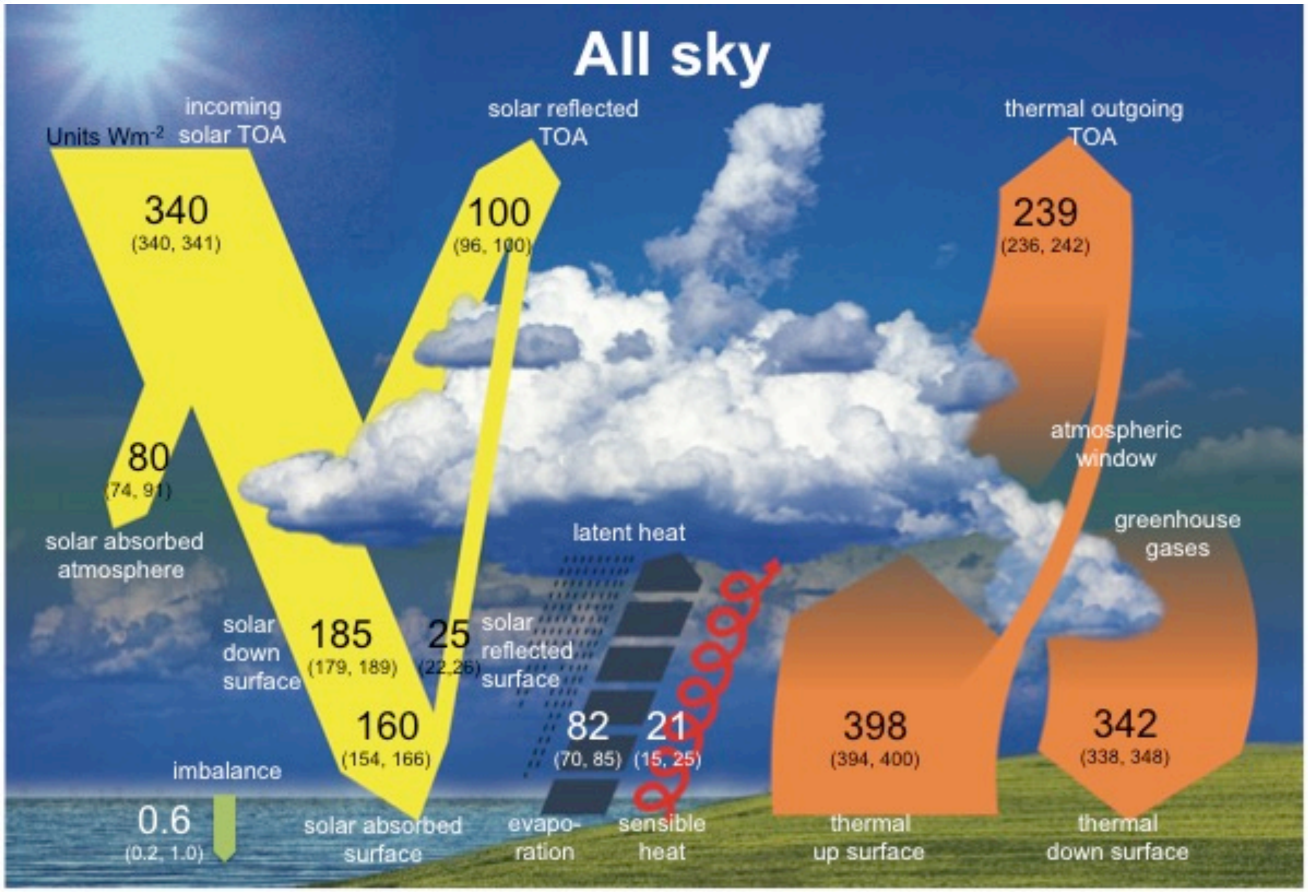

Surface fluxes from surface station observations

IPCC AR5 Fig. 2.11 / Wild et al. 2013, 2015 Climate Dynamics

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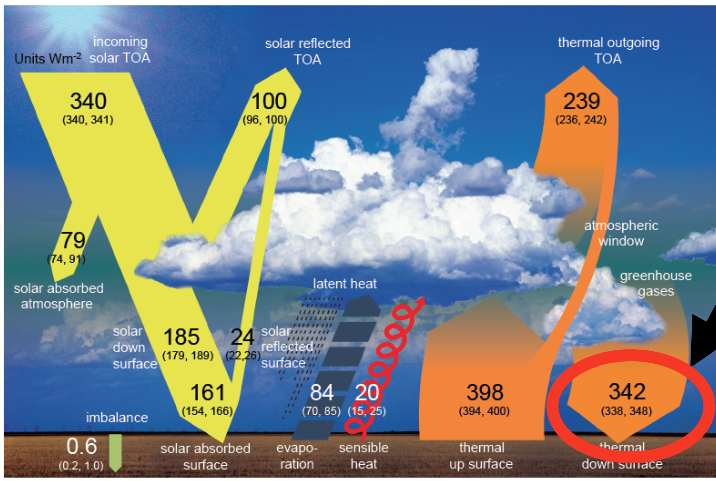
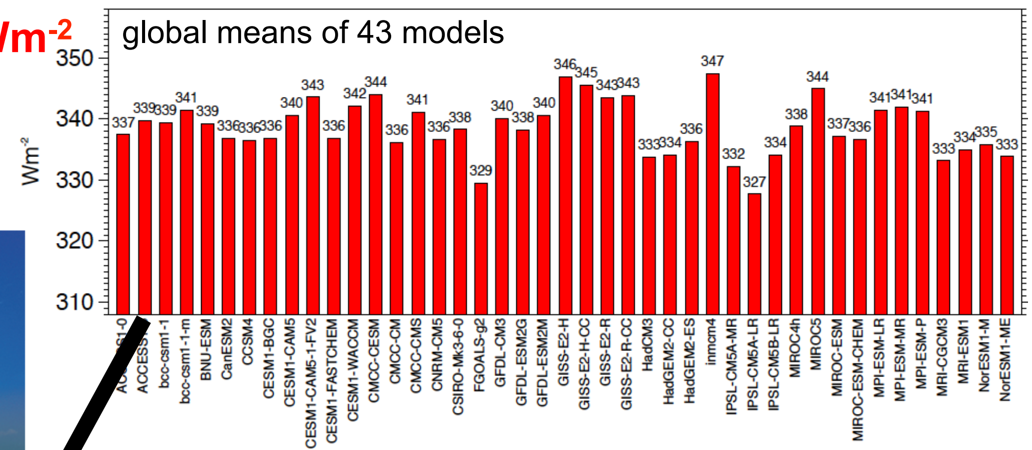
Surface radiation budgets in CMIP5 GCMs

Model mean 339 Wm^{-2}
Model range: 20 Wm^{-2}
Standard dev.: 4.4 Wm^{-2}



Downward longwave radiation



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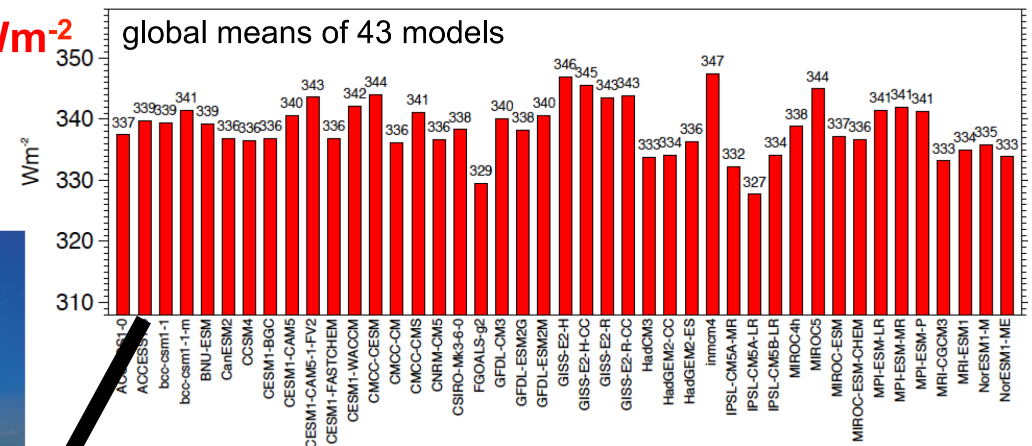
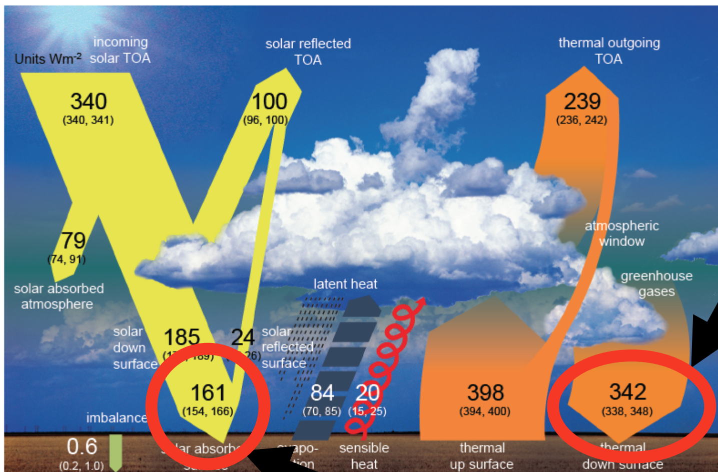
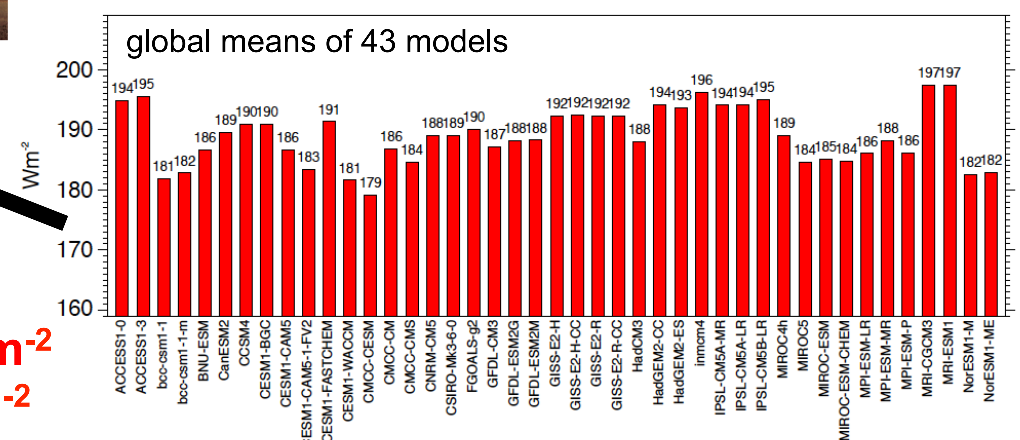




Downward shortwave radiation



Model mean: 189 Wm^{-2}
Model range: 18 Wm^{-2}
Standard dev.: 4.7 Wm^{-2}

Wild et al. 2013, Climate Dynamics

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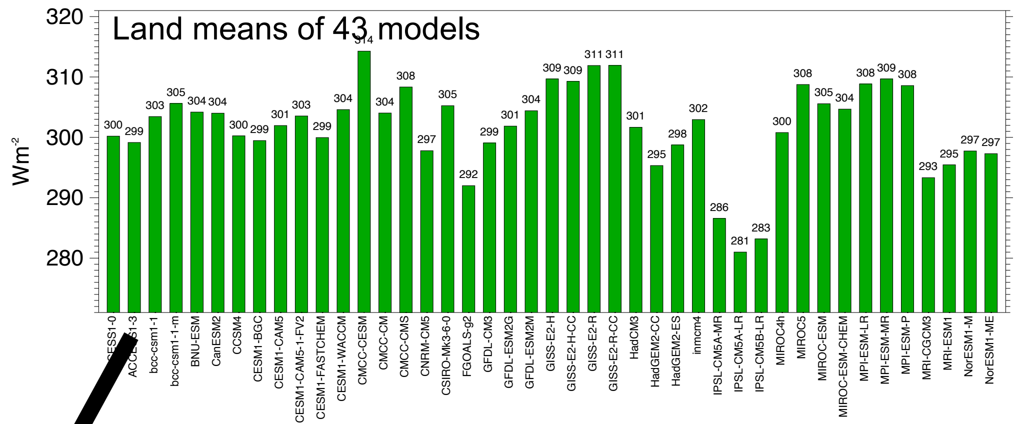
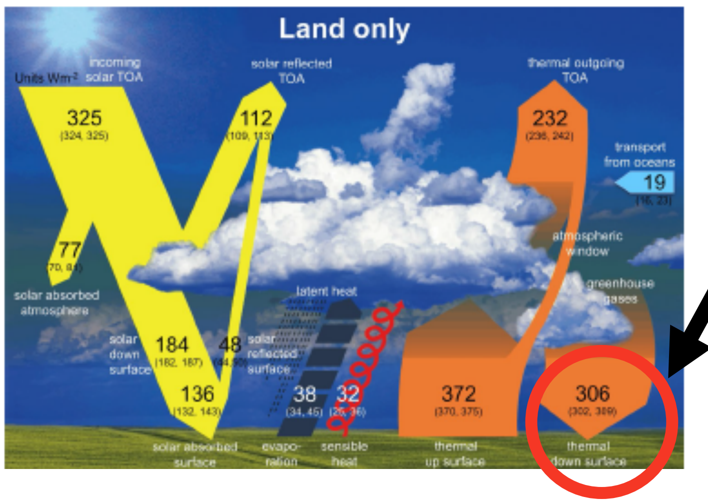
Land mean surface energy balance in CMIP5 GCMs

Model mean 302 Wm^{-2}
Model range: 33 Wm^{-2}
Standard dev.: 7.2 Wm^{-2}

Downward longwave radiation surface





Wild et al. 2015, Clim. Dyn.

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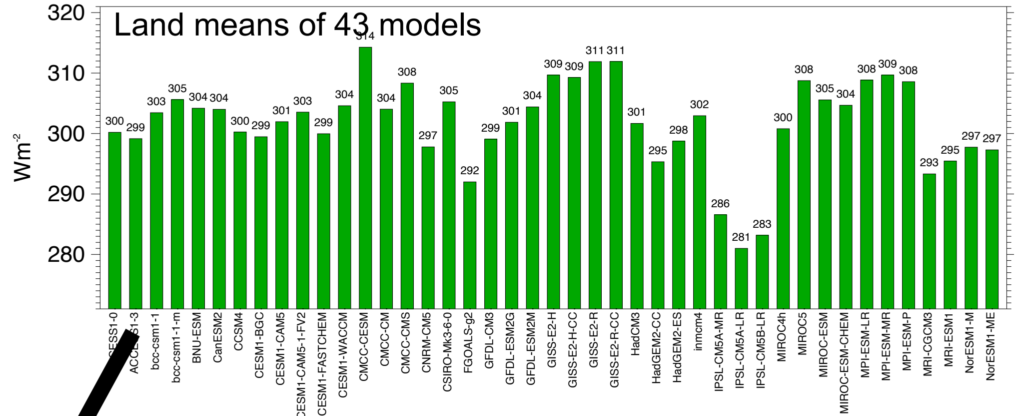
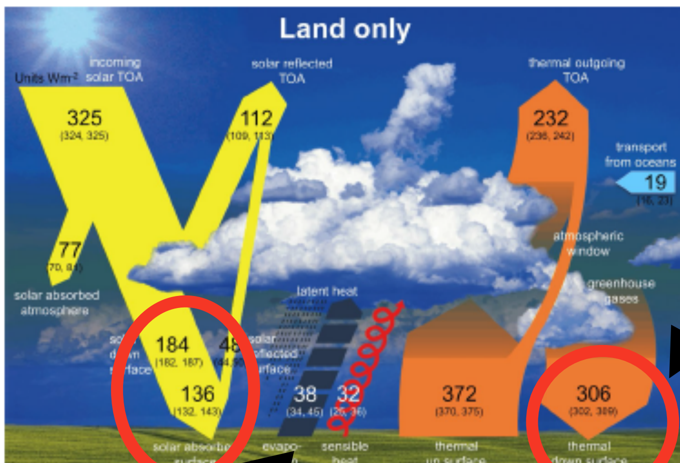
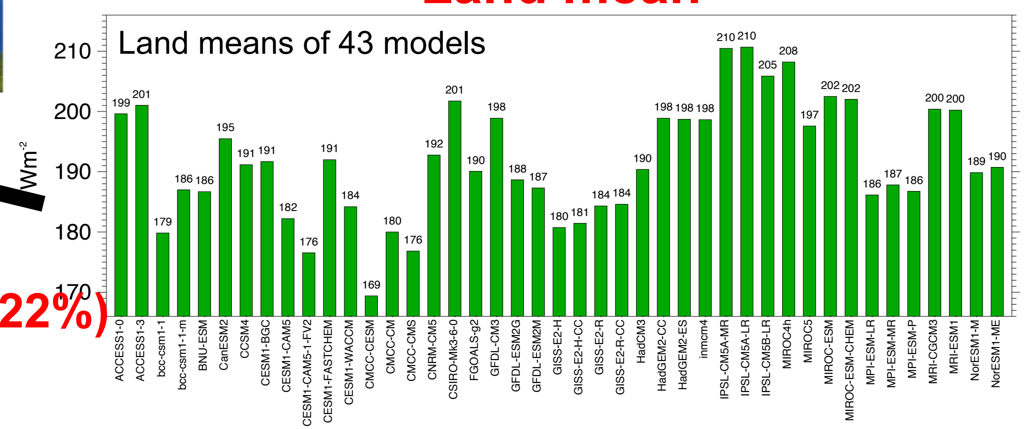
Downward longwave radiation
Land mean





Downward shortwave radiation
Land mean



Model mean: 192 Wm^{-2}
Model range: 42 Wm^{-2} (22%)
Standard dev.: 10 Wm^{-2}

=> Large discrepancies in surface radiative fluxes in CMIP5 models

Wild et al. 2015, Clim. Dyn.

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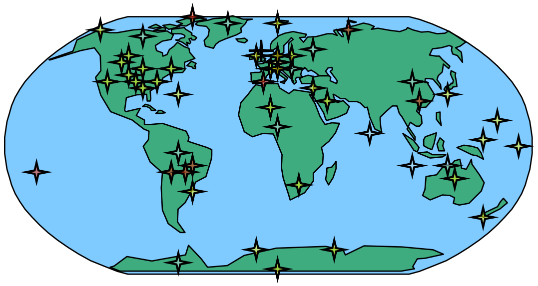
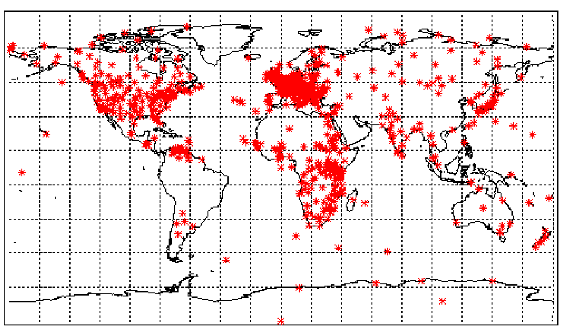
Constraints from surface observations



Ohmura et al. 1998 BAMS
Driemel et al. 2018 ESSD



Wild et al. 2017, ESSD

BSRN Baseline Surface Radiation Network

- WCRP initiative, starting in 1992
- Highest measurement quality at selected sites worldwide (currently 64 anchor sites)
- Minute values
- Ancillary data for radiation interpretation

GEBA Global Energy Balance Archive

- Worldwide measurements of historic energy fluxes at the surface (2500 sites)
- Solar radiation data at many sites since 1950s, some back to 1930s
- Monthly mean values
- www.geba.ethz.ch

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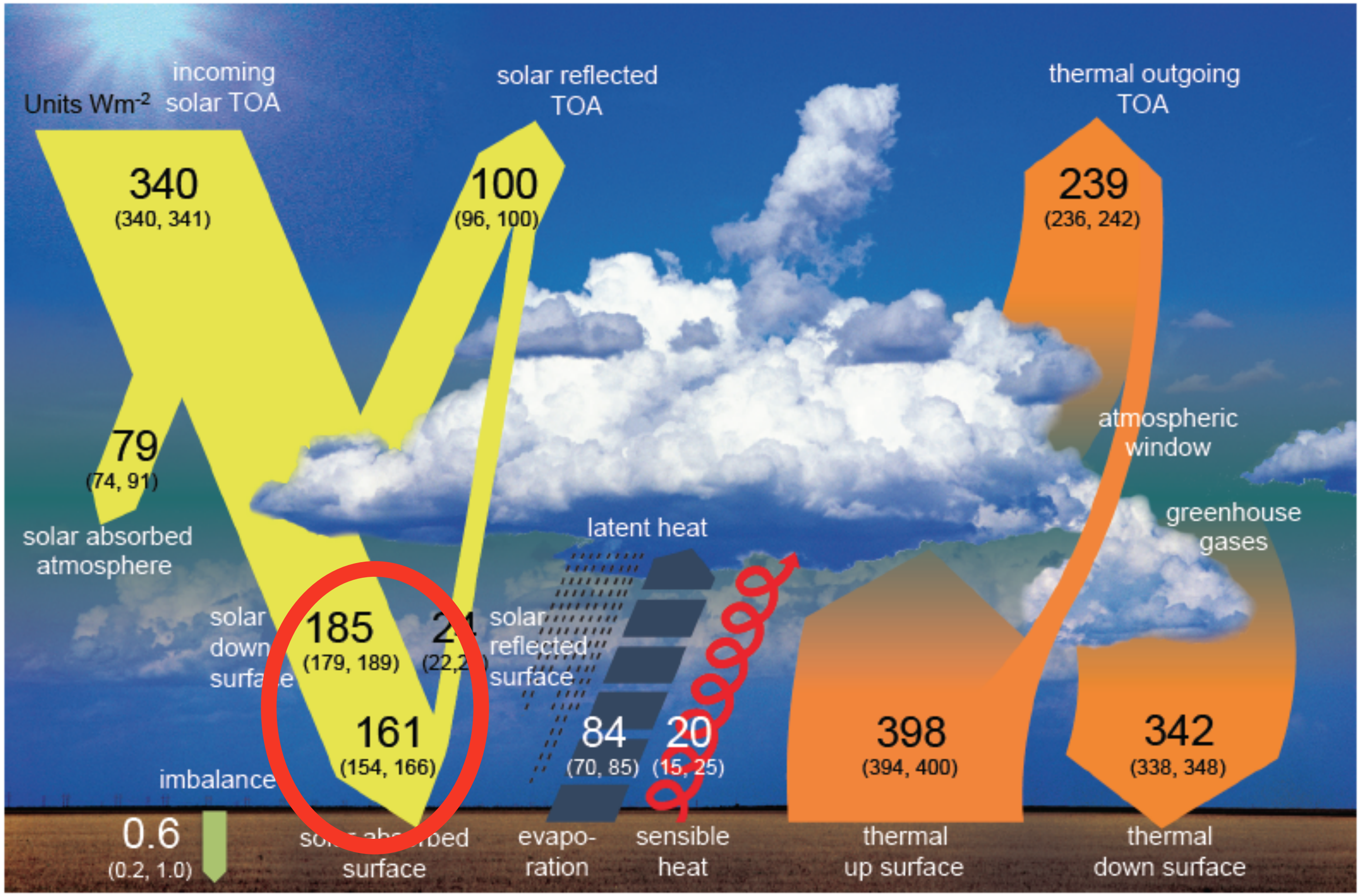
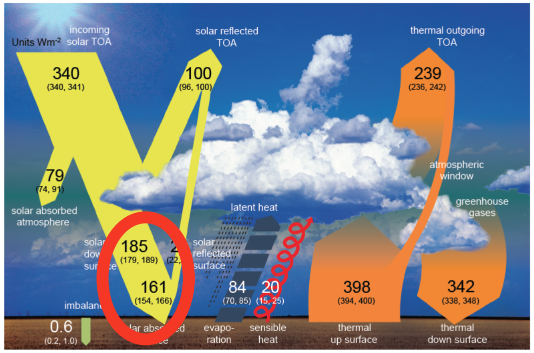
Evaluation of CMIP5 surface radiation balance

Assessment of downward shortwave radiation in climate models using BSRN data

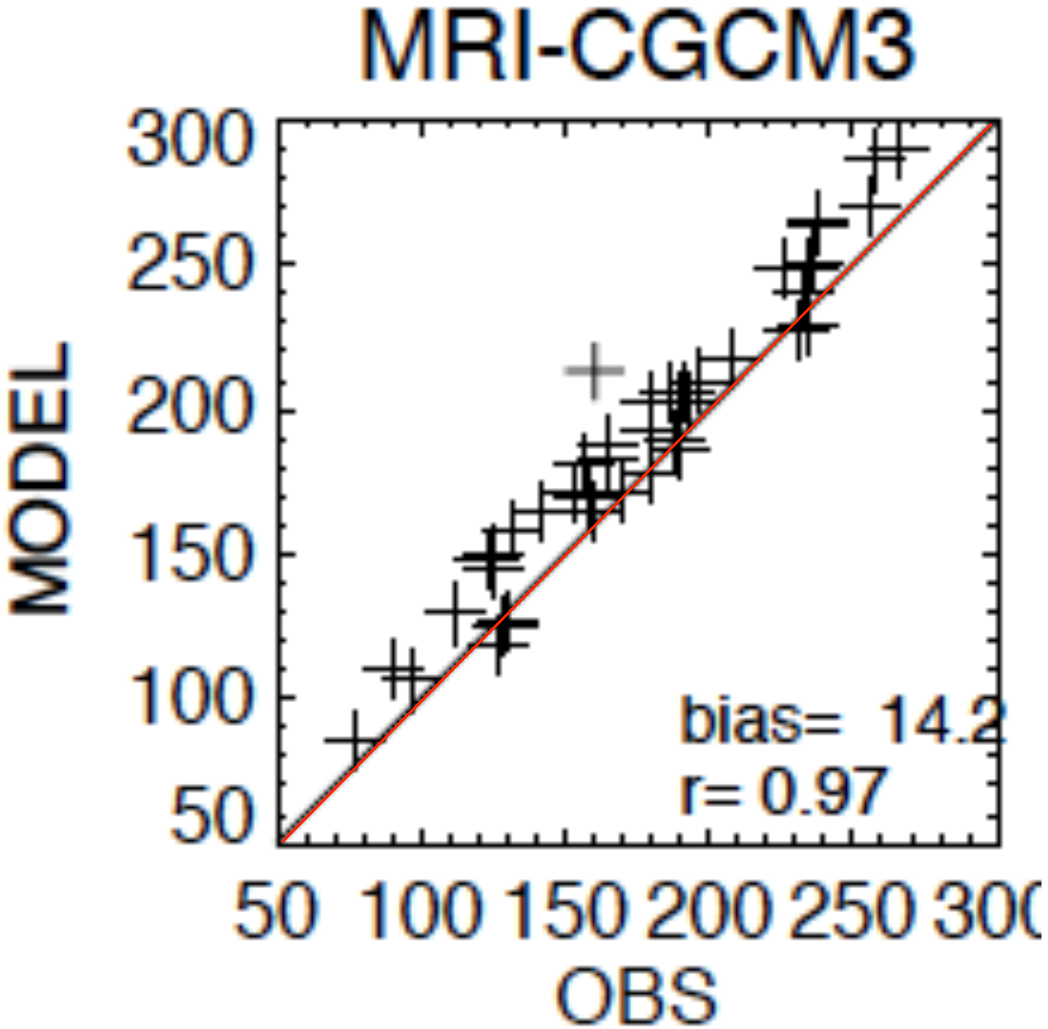


Evaluation of CMIP5 surface radiation balance



SW down

42 BSRN sites



Constraining surface fluxes with BSRN obs:

Most models overestimate surface SW down

Wild et al., Climate Dynamics

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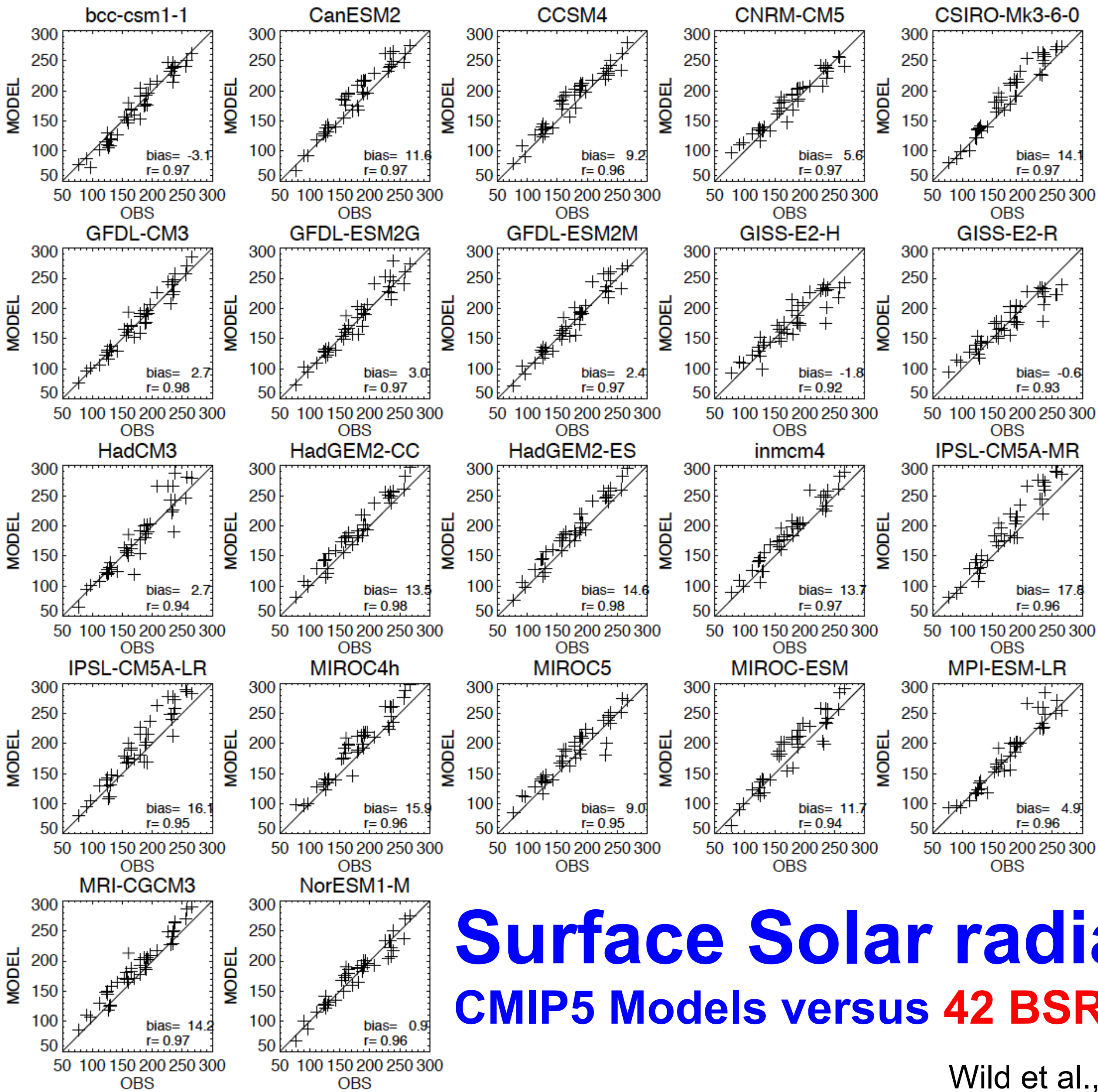
Evaluation of CMIP5 surface radiation balance



Surface Solar radiation:

CMIP5 Models versus 42 BSRN stations

Wild et al., Climate Dynamics

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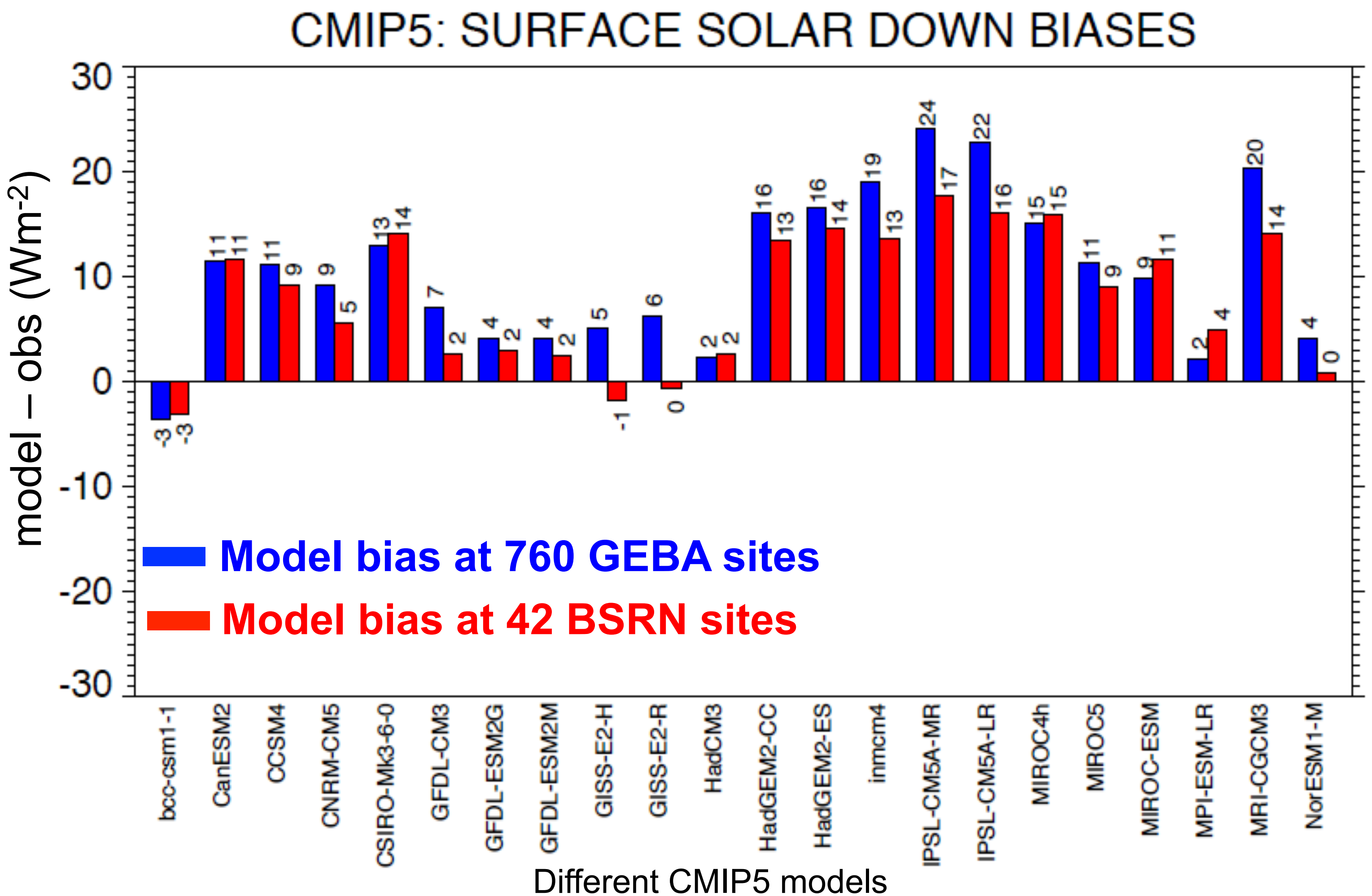
Evaluation of CMIP5 surface radiation balance



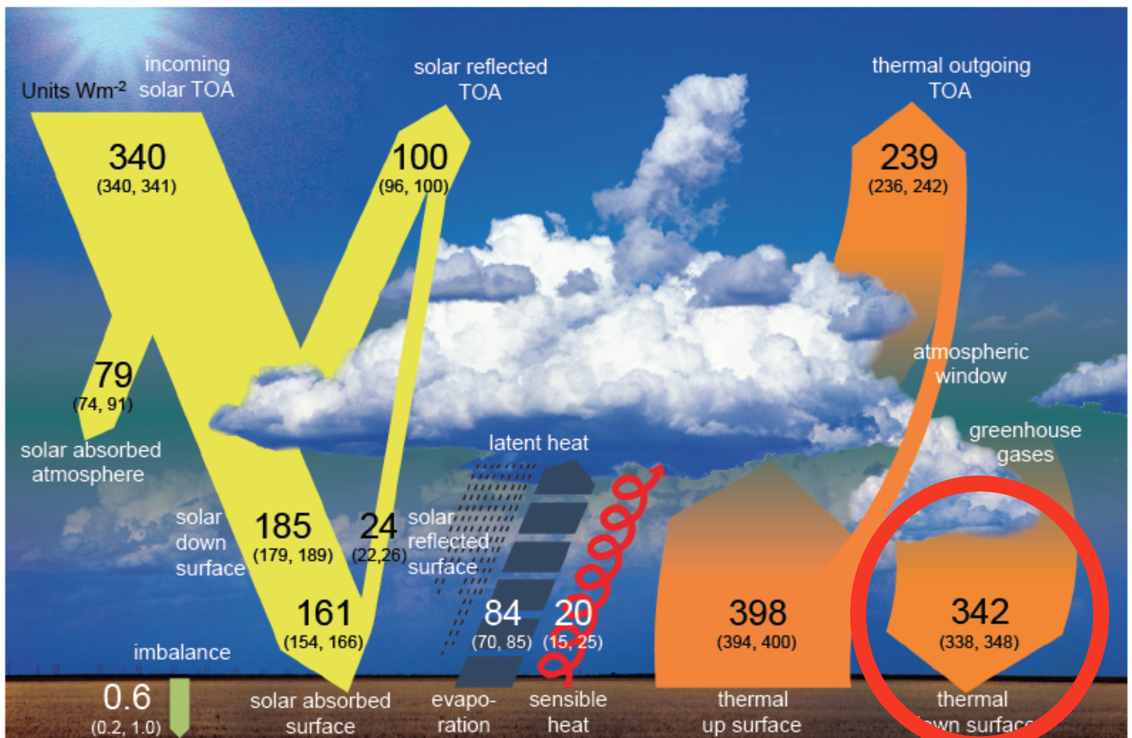
Multimodel mean bias SW_{down} at 760 GEBA sites: +10 Wm^{-2}

Multimodel mean bias SW_{down} at 42 BSRN sites: +8 Wm^{-2}

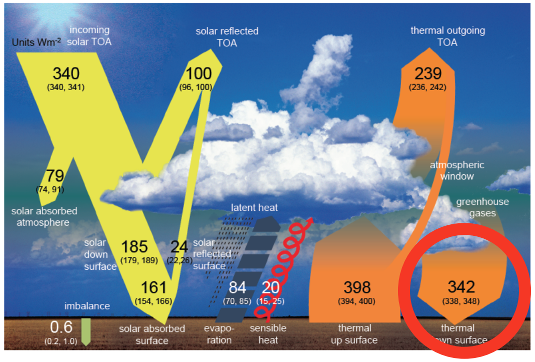
Wild et al., Climate Dynamics

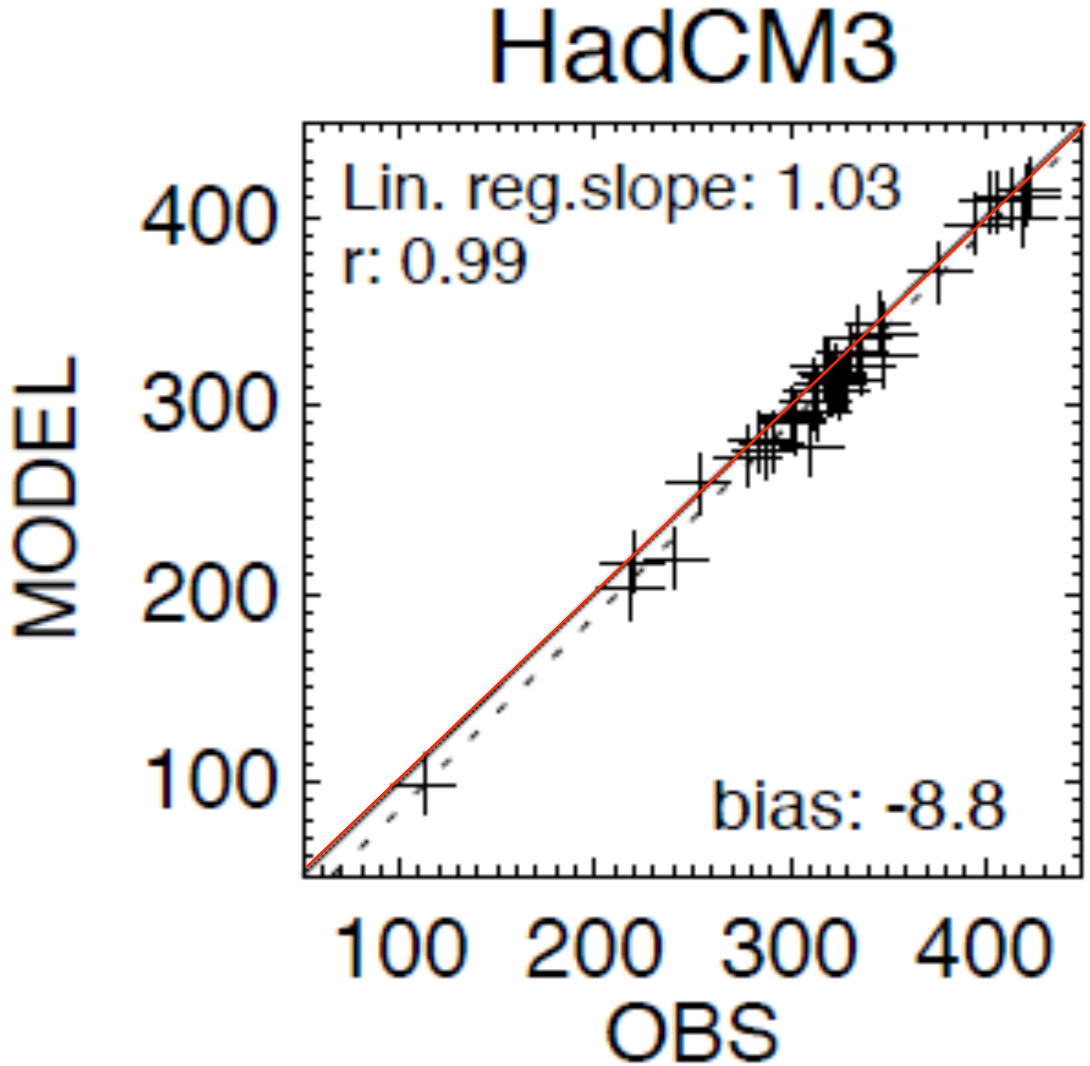
Evaluation of CMIP5 surface radiation balance

Assessment of downward longwave radiation



Evaluation of CMIP5 surface radiation balance





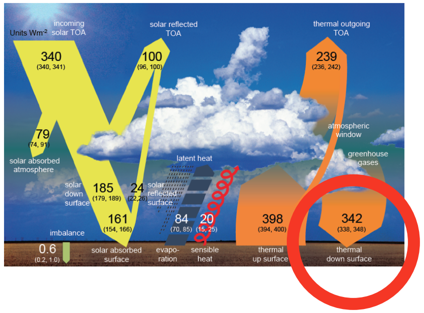
LW down

41 BSRN sites

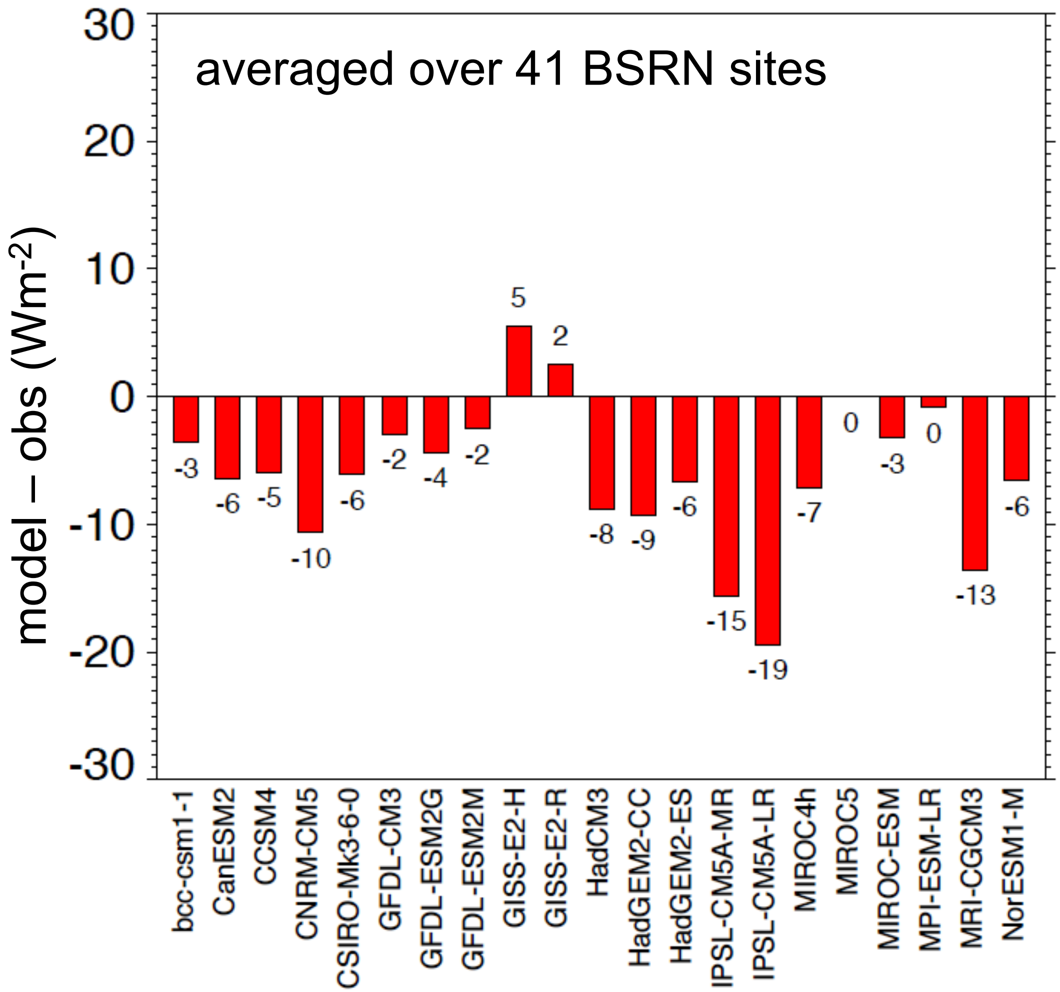
Constraining surface fluxes with BSRN observations: CMIP5 models typically underestimate LW down

Wild et al., Climate Dynamics

Evaluation of CMIP5 surface radiation balance



GCM LWdown biases at BSRN sites



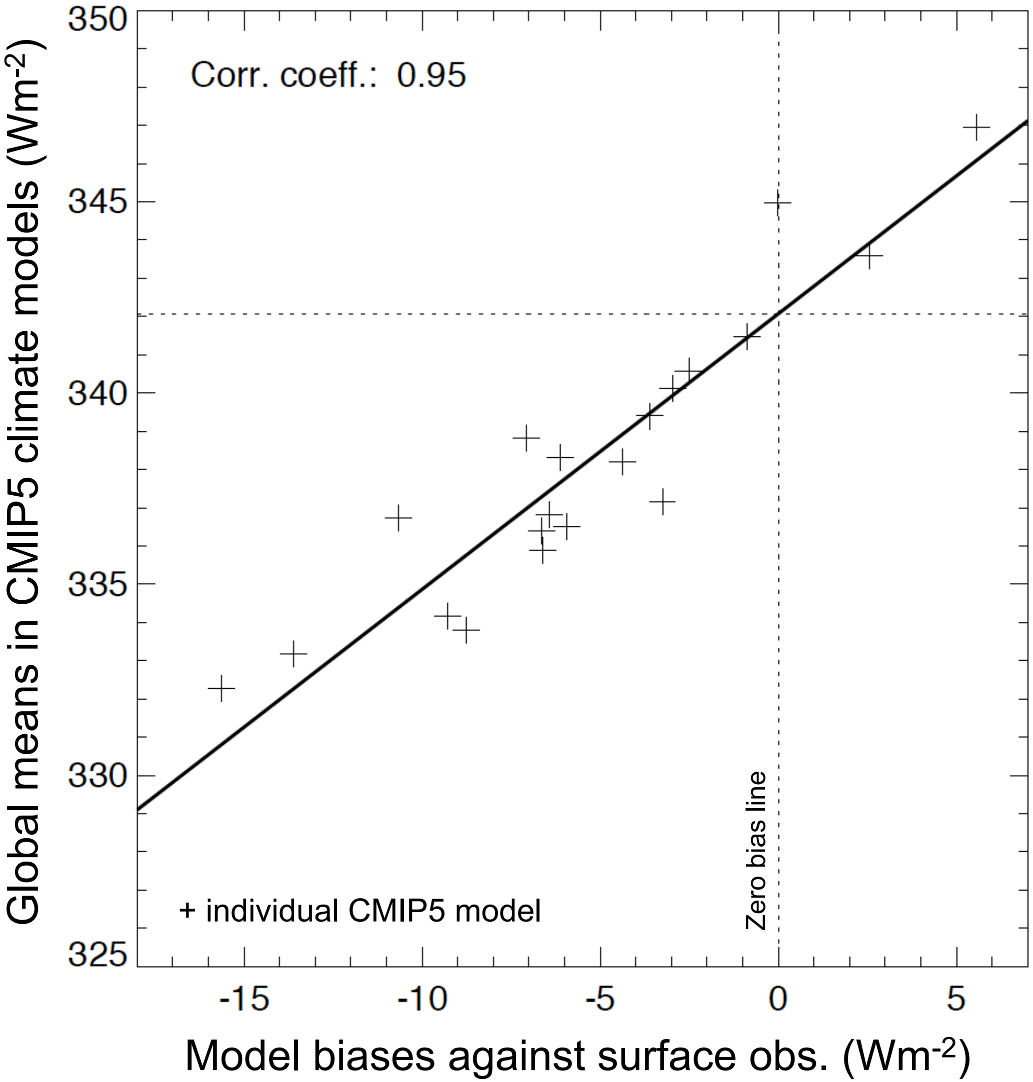
Mean model bias LWdown at 41 BSRN sites: -6 Wm^{-2}

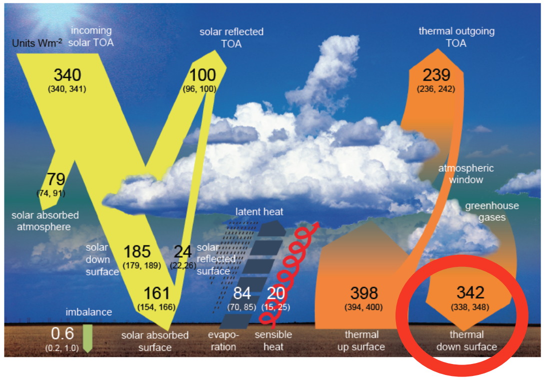
Wild et al., Climate Dynamics

Best estimates for global mean LW down

Surface LW down global mean

GCM global means versus their biases averaged over 41 BSRN sites





Wild et al., Climate Dynamics

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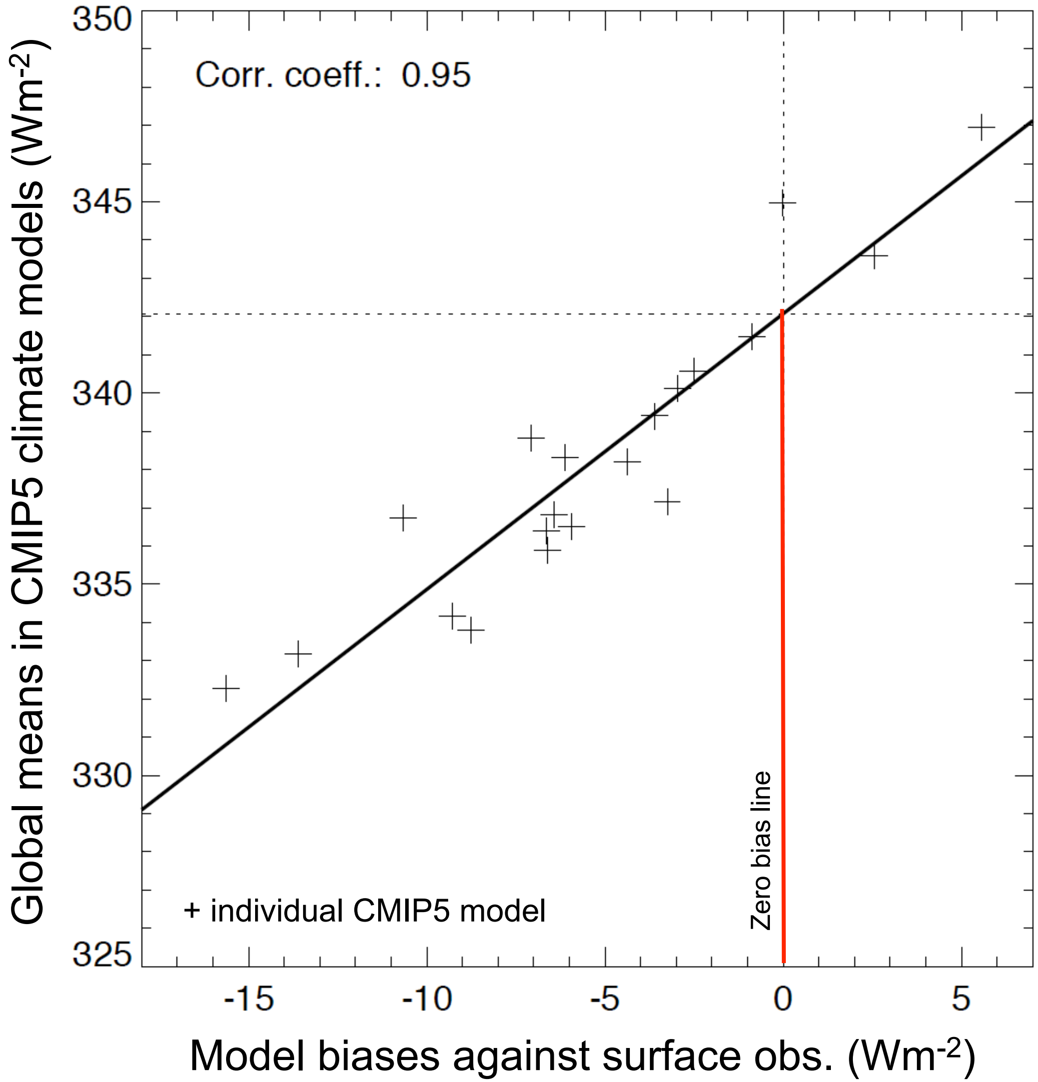

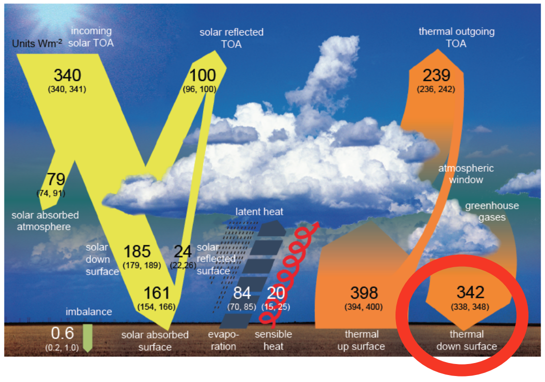

Wild et al., Climate Dynamics

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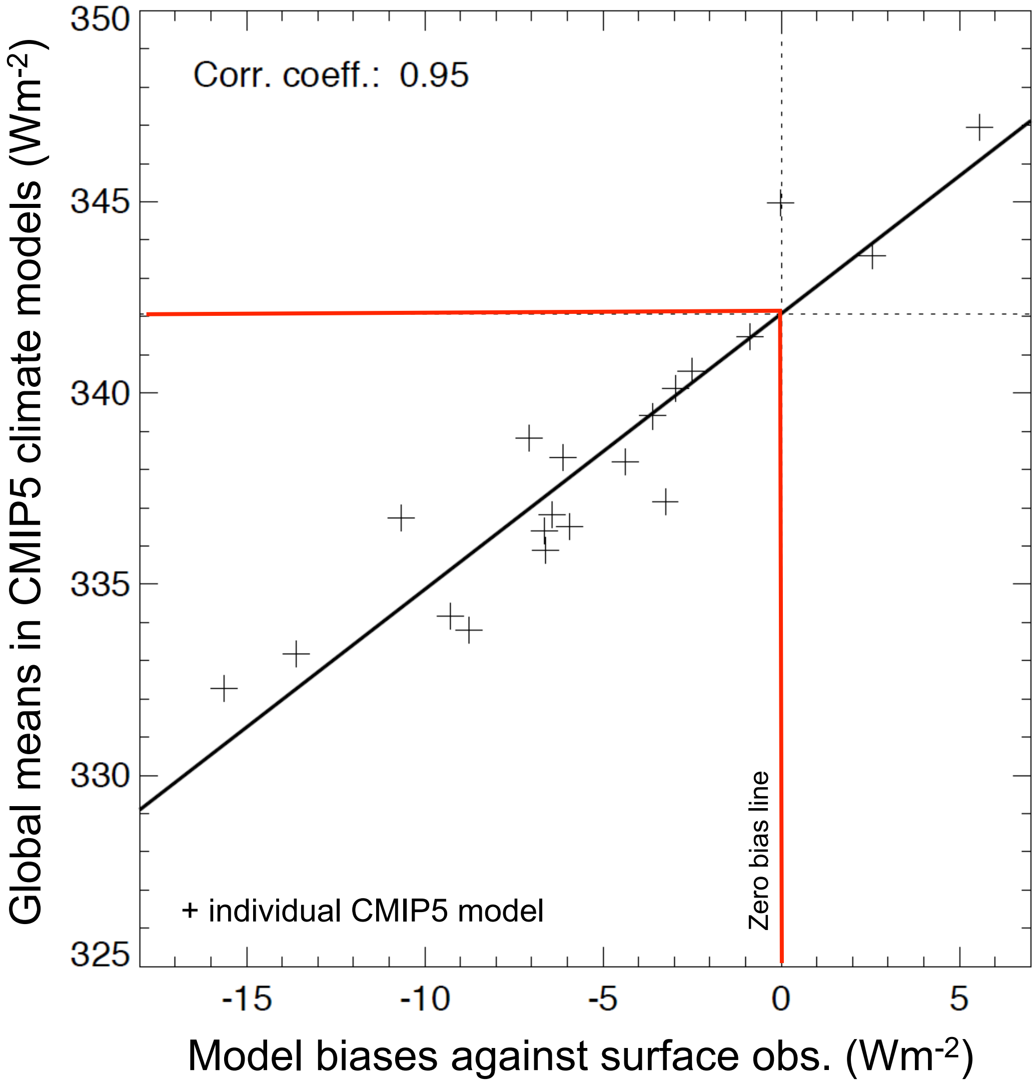
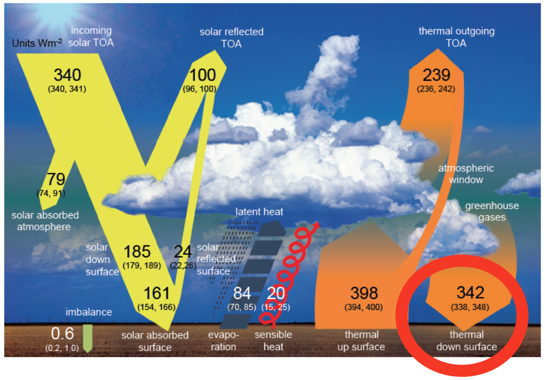


Best estimate surface LW down: 342 Wm^{-2}



Wild et al., Climate Dynamics

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Best estimates for global mean LW down

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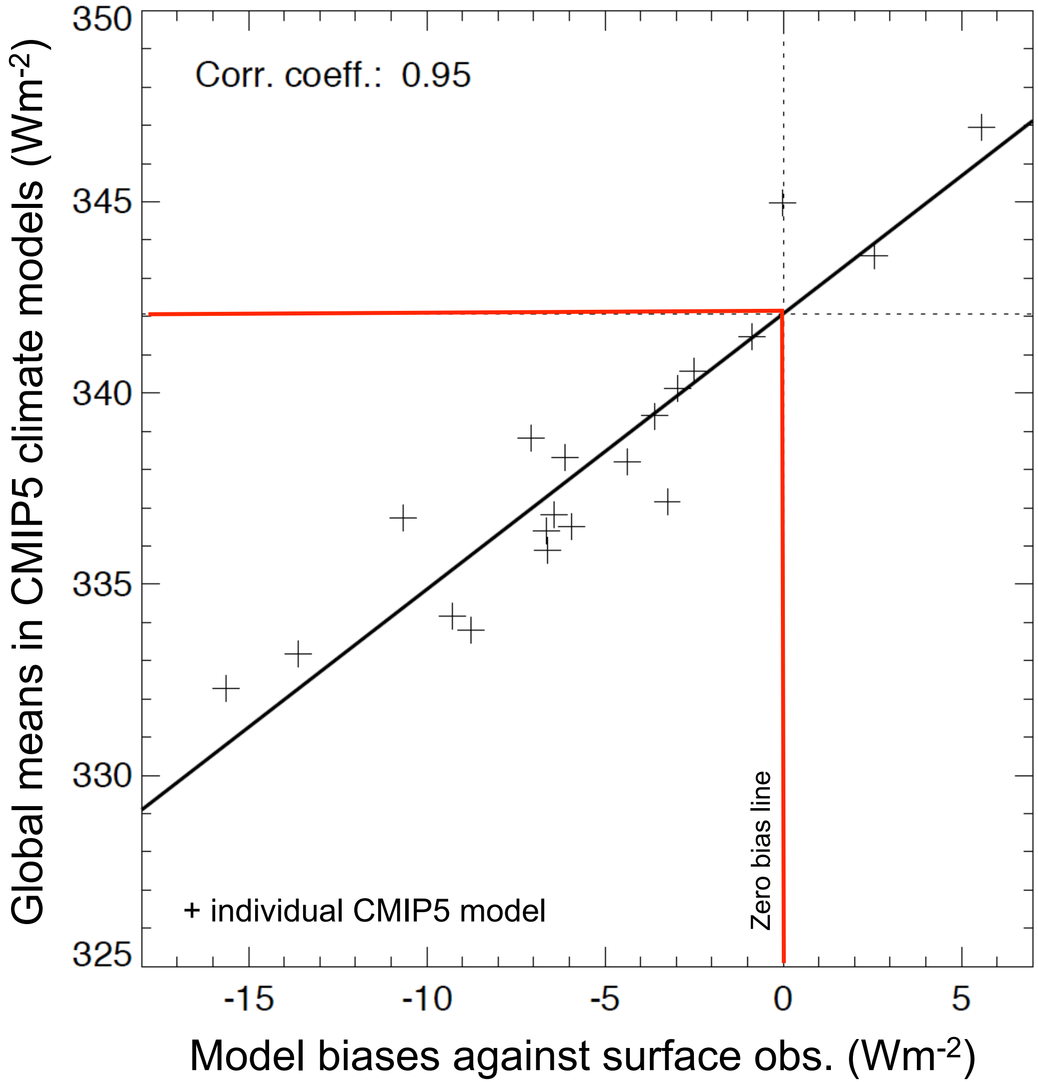
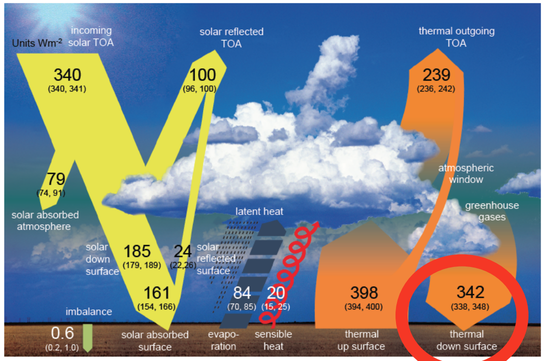


Best estimate surface LW down: ***342 Wm^{-2}***

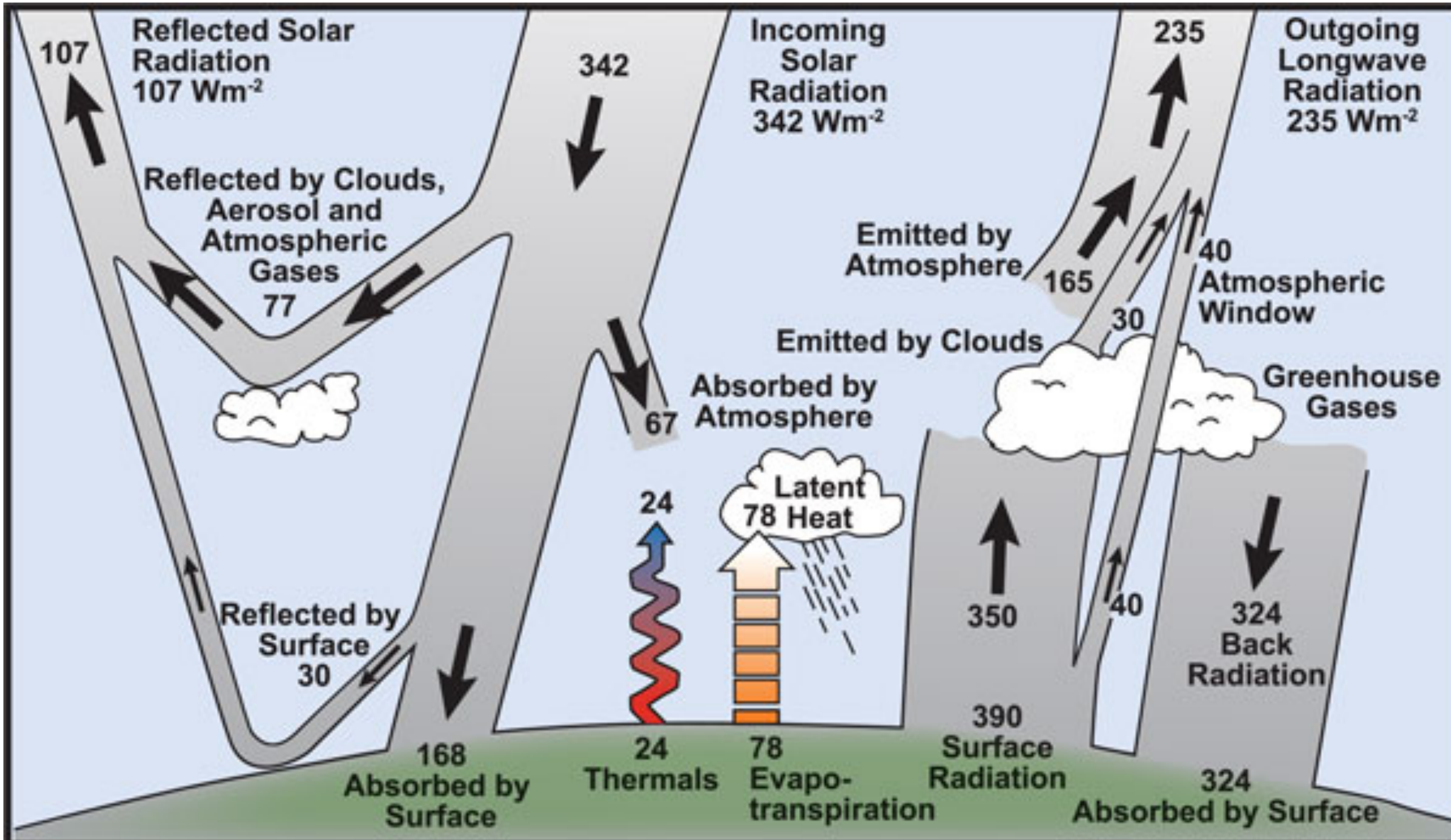
c.f. CERES/EBAF satellite-derived estimate: *344 Wm^{-2}* (Kato et al. 2012)



Wild et al., Climate Dynamics

Revision of IPCC AR4 Energy Balance Figure

Units Wm^{-2}

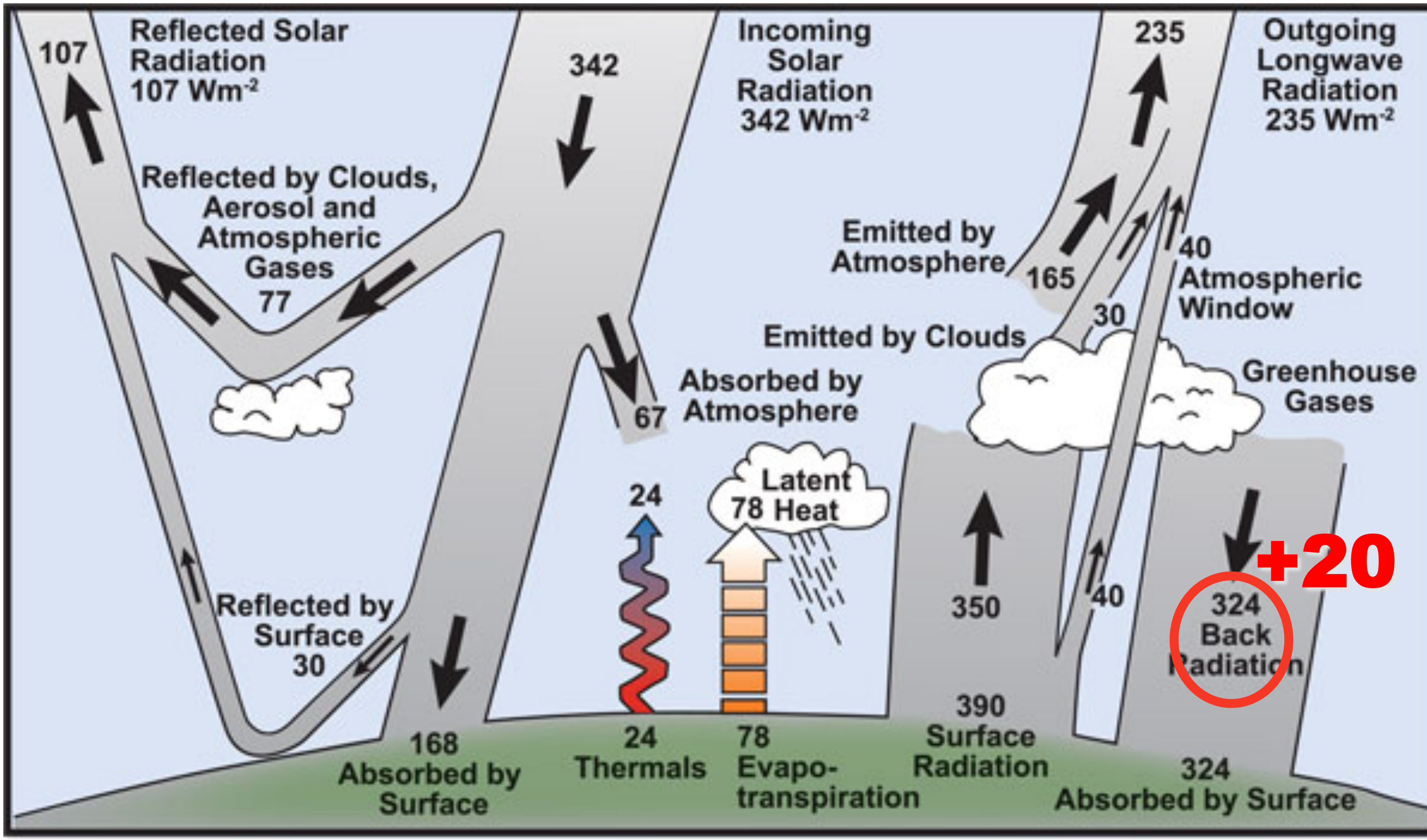


IPCC AR4, based on Kiehl and Trenberth

Wild 2012: A facelift for the picture of the global energy balance, *Atmos. Environ.* **55**

Revision of IPCC AR4 Energy Balance Figure

Units Wm^{-2}



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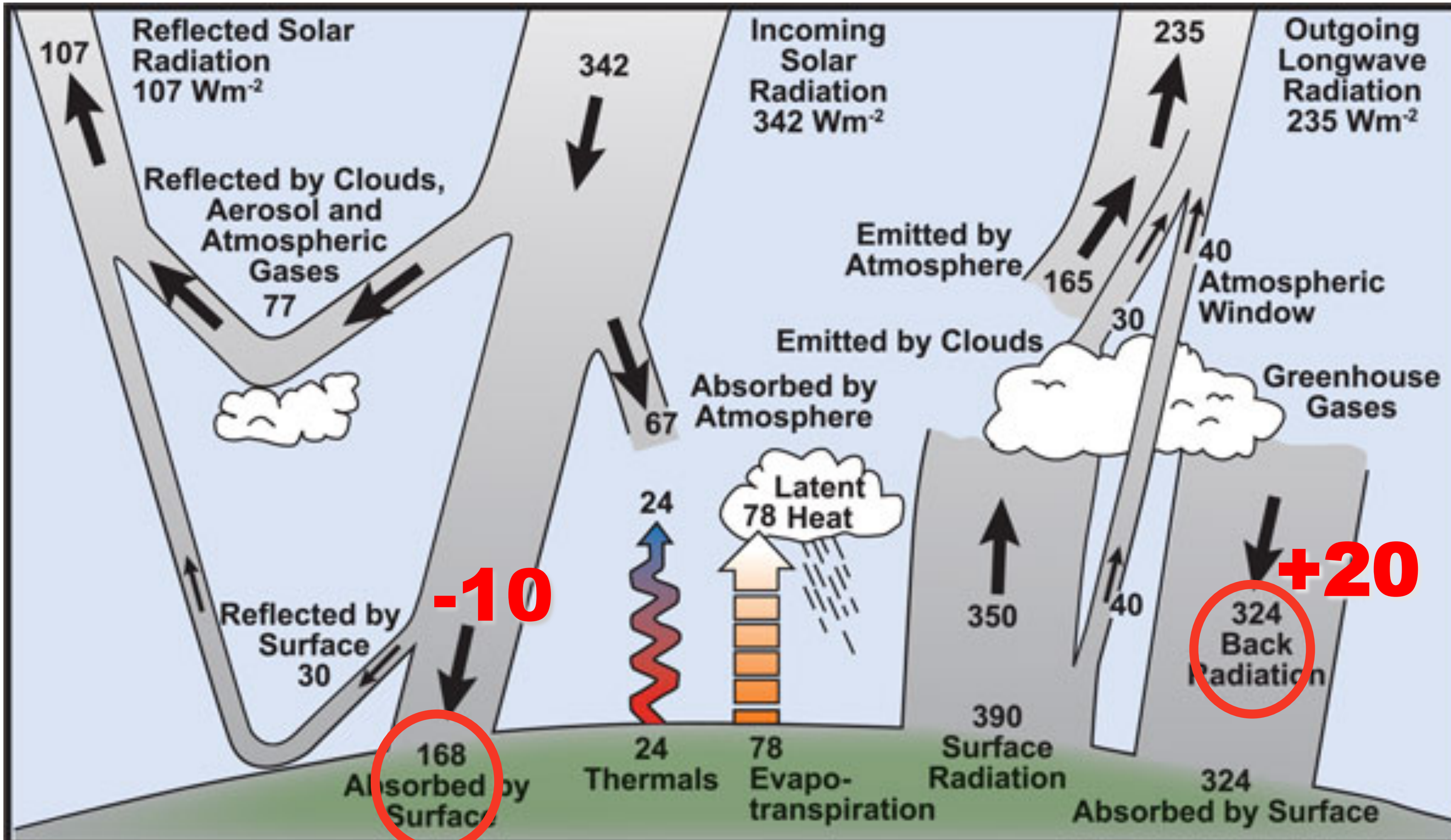


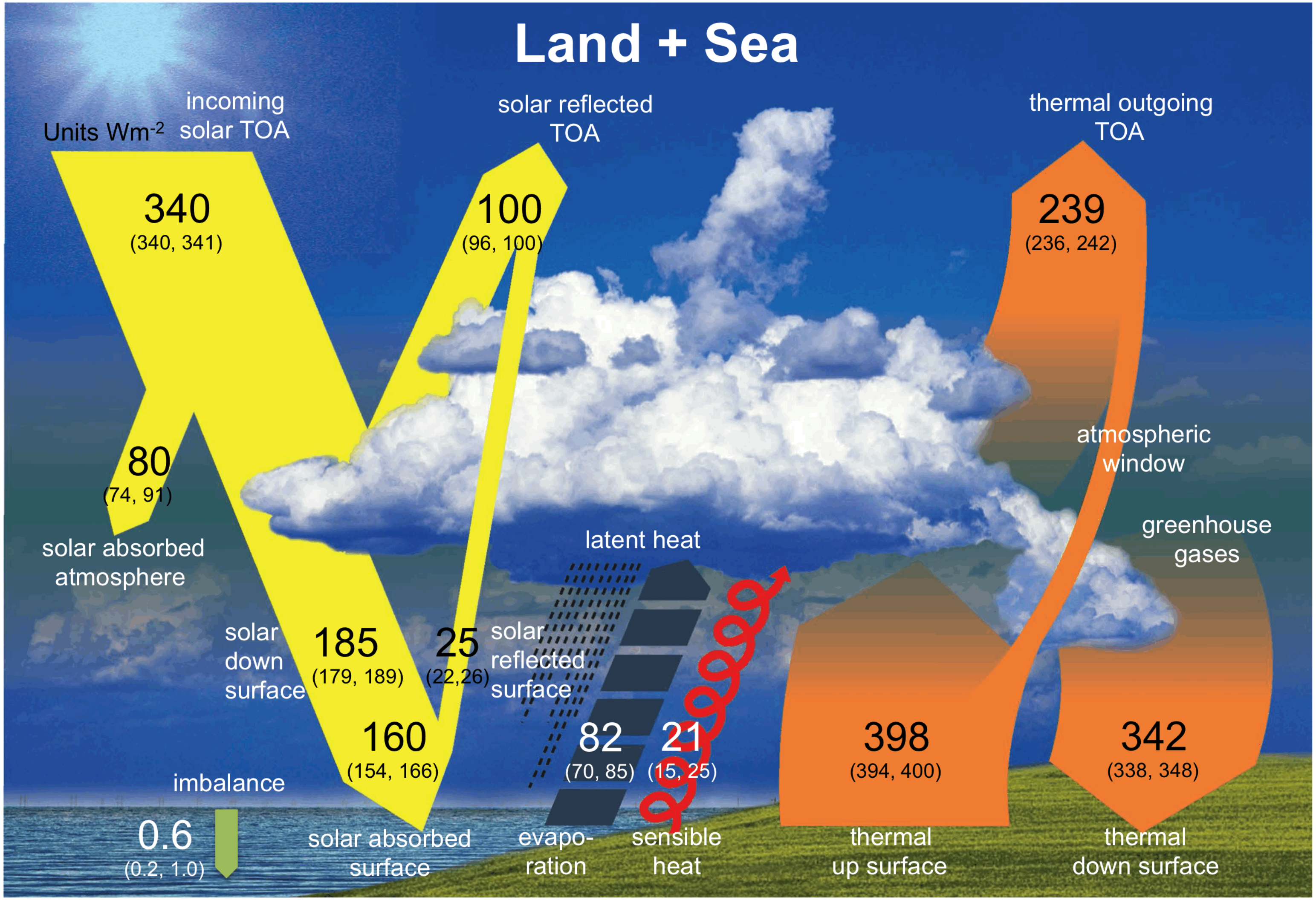
IPCC AR4, based on Kiehl and Trenberth

Wild 2012: A facelift for the picture of the global energy balance, *Atmos. Environ.* **55**

Global Energy Balance (update for IPCC AR5)

Flux estimates consistent with BSRN observations

Units Wm^{-2}



IPCC AR5 / Wild et al. 2013, 2015 Clim. Dyn.

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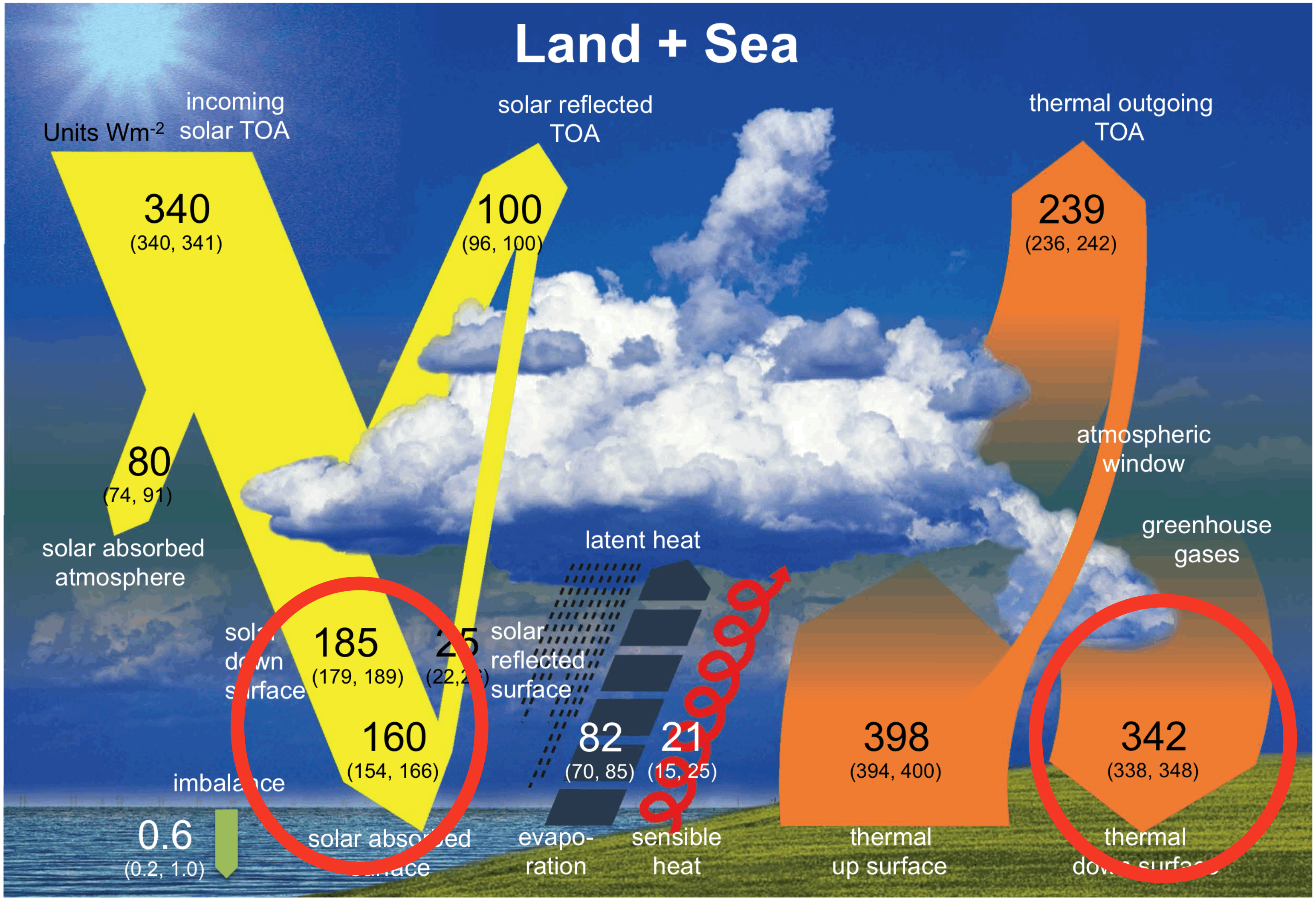
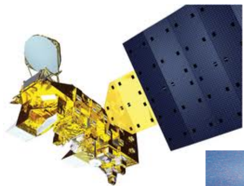


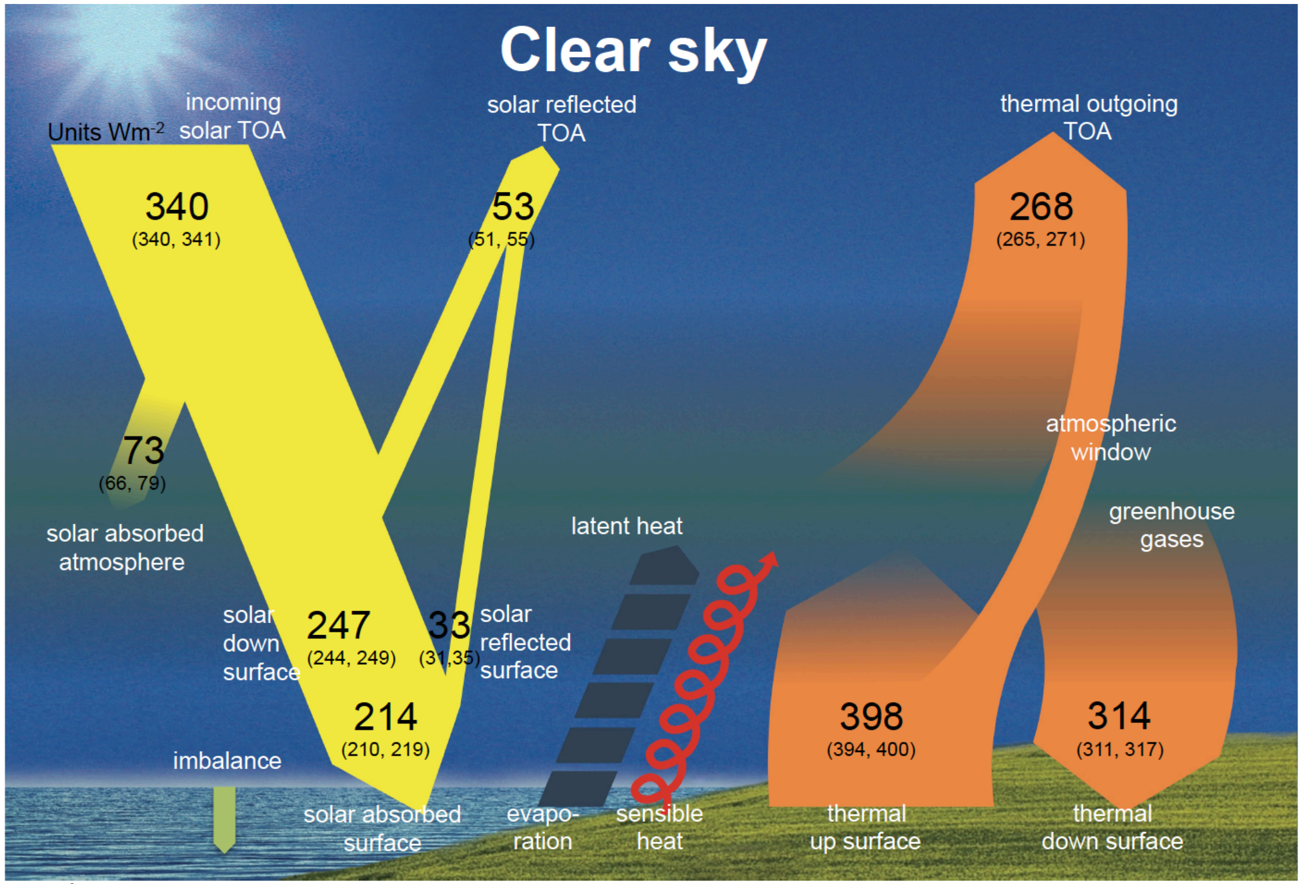
IPCC AR5 / Wild et al. 2013, 2015 Clim. Dyn.

Earth Radiation Budget without clouds



TOA fluxes from CERES satellite data

Units Wm^{-2}



Surface fluxes from BSRN observations

Wild et al. 2018, under review in Climate Dynamics

Estimating clear-sky climatologies at BSRN sites

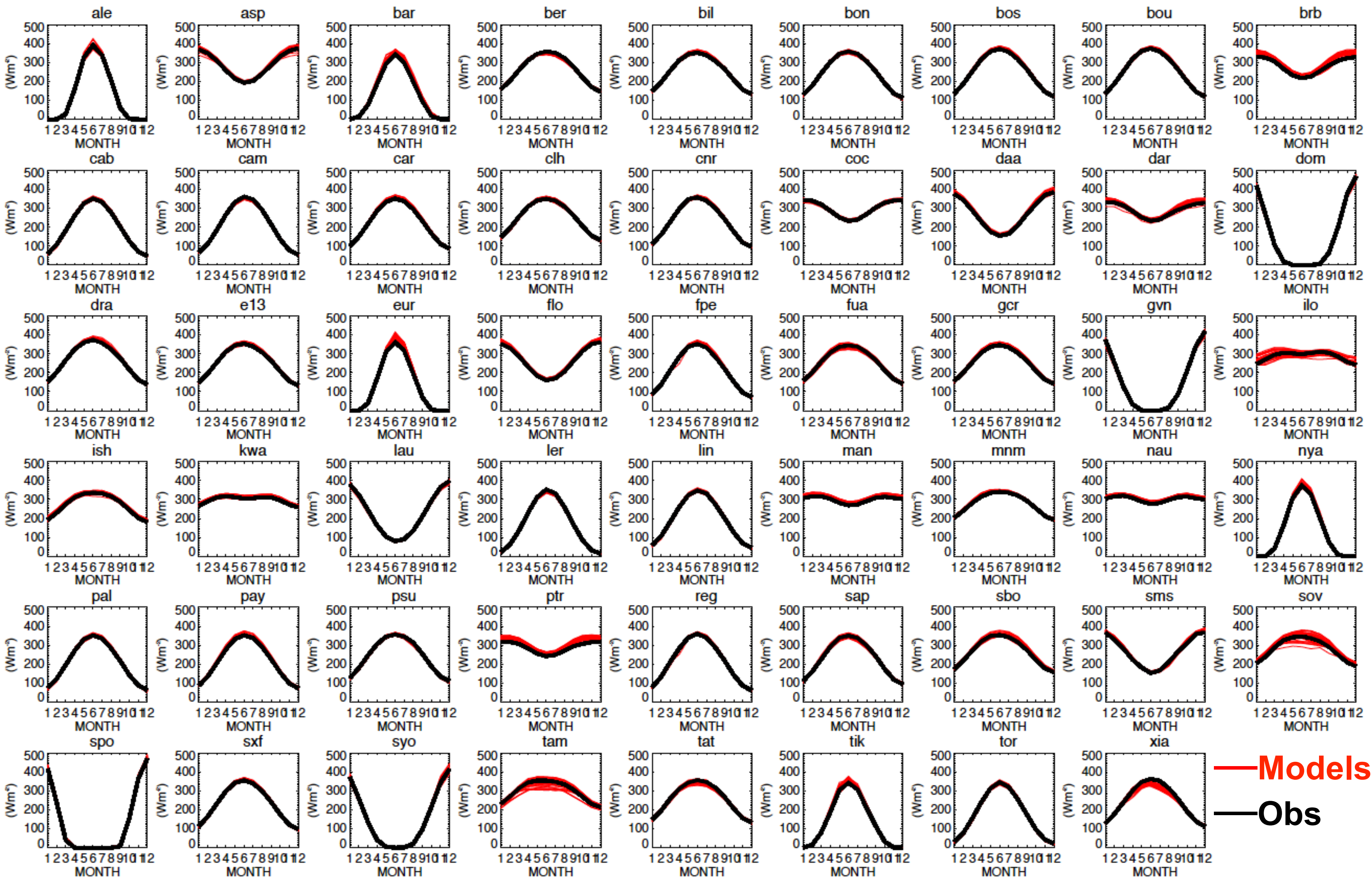
High resolution BSRN records (minute data) used to establish clear sky estimates

SW clear sky detection algorithm
Long and Ackerman (2002) JGR
Takes into account magnitude and temporal variability of diffuse and total downward solar radiation

LW clear sky detection algorithm
Long and Turner (2008) JGR
Makes use of clear episodes detected by the SW algorithm and takes into account variability of downward longwave radiation, measured ambient air temperature and effective sky brightness temperature.

Clear sky BSRN data processed at ETH Zurich by Maria Hakuba with support from Chuck Long

SW down clear sky evaluation



39 CMIP5 models at 53 BSRN sites

Wild et al. 2018, under review in Climate Dynamics

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Caveats when comparing models with observations

Modellers' clear sky not equal observers' clear sky

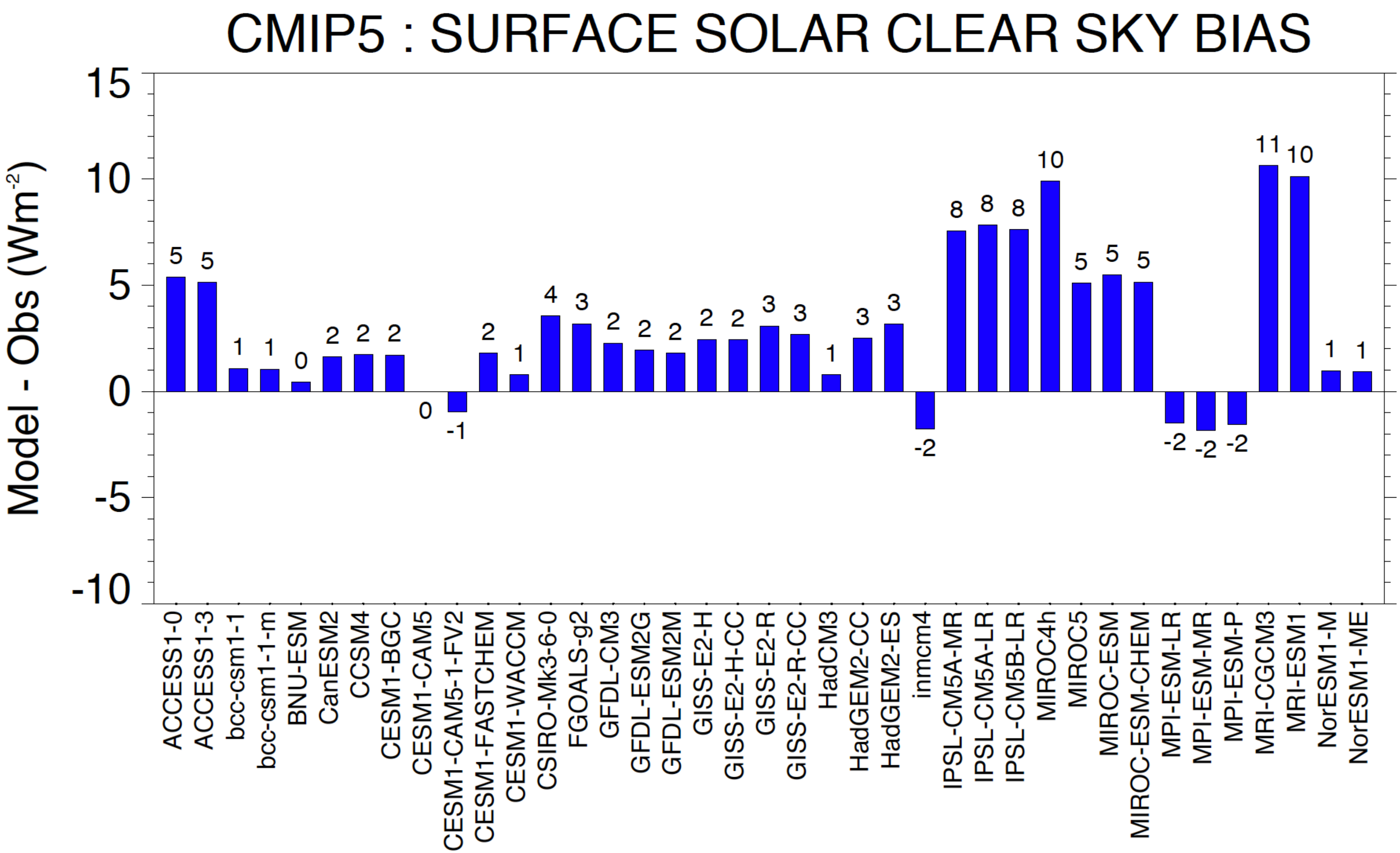
Observers' clear sky radiation: *only from episodes with no clouds*
Modellers' clear sky radiation: *every model time step, just without clouds*

- Correction required > estimated at ~ 2 Wm^{-2} for surface solar radiation (site dependent). Based on an analysis of true cloud free periods in multi-century climate model control simulations

Representativeness of surface observation stations for model gridbox

- **Poster 295 by Matthias Schwarz,**
  From Point to Area: Worldwide Representativeness of Monthly Surface Solar Radiation Records
  On display Wednesday

SW down clear sky evaluation



Individual CMIP5 model biases averaged over 53 BSRN sites

Wild et al. 2018, under review in Climate Dynamics

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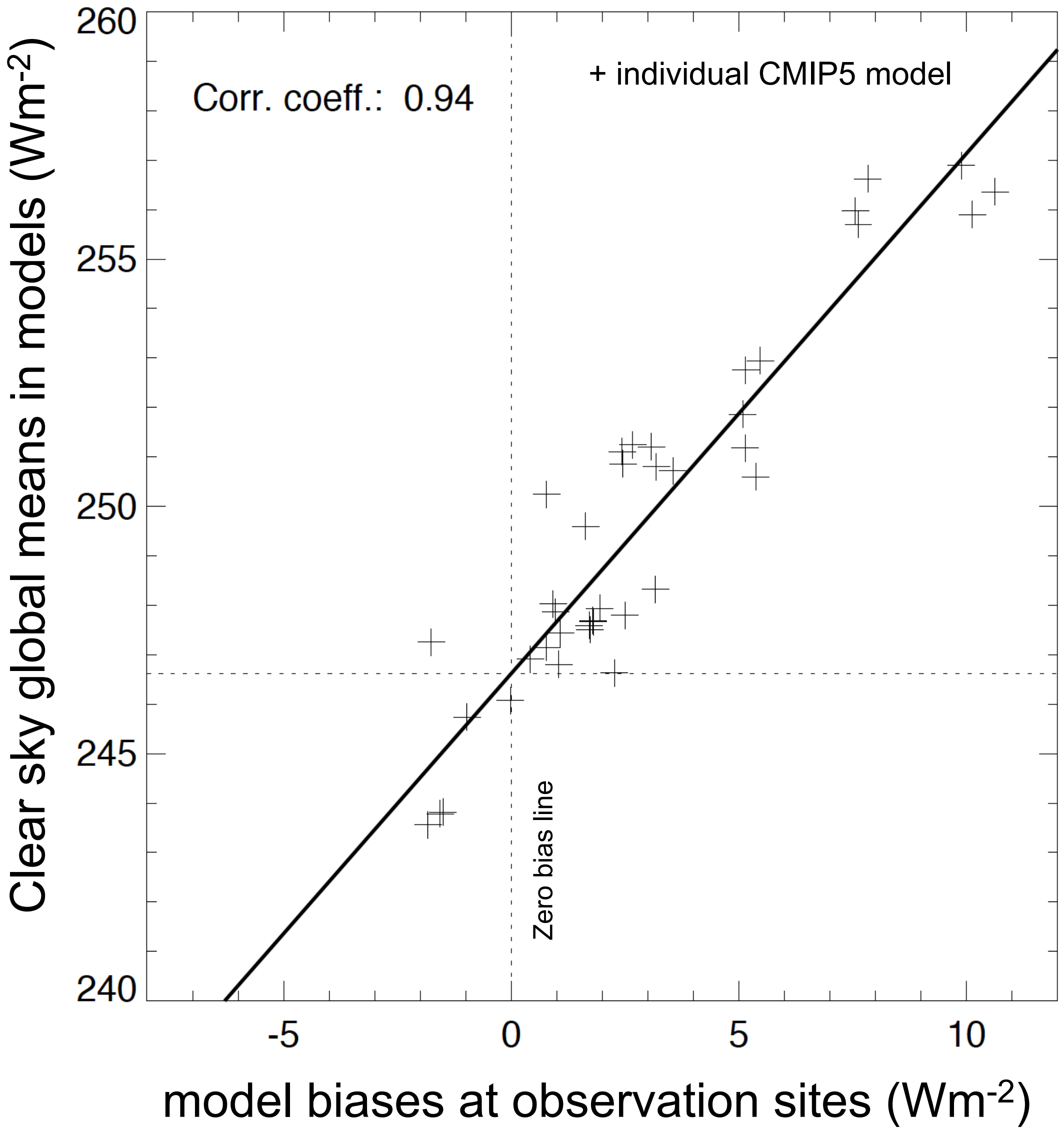
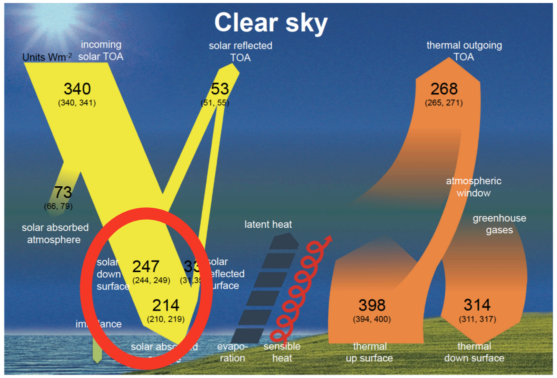
Best estimates for global mean clear sky fluxes

Surface SW down clear sky

GCM global means versus their biases averaged over BSRN sites





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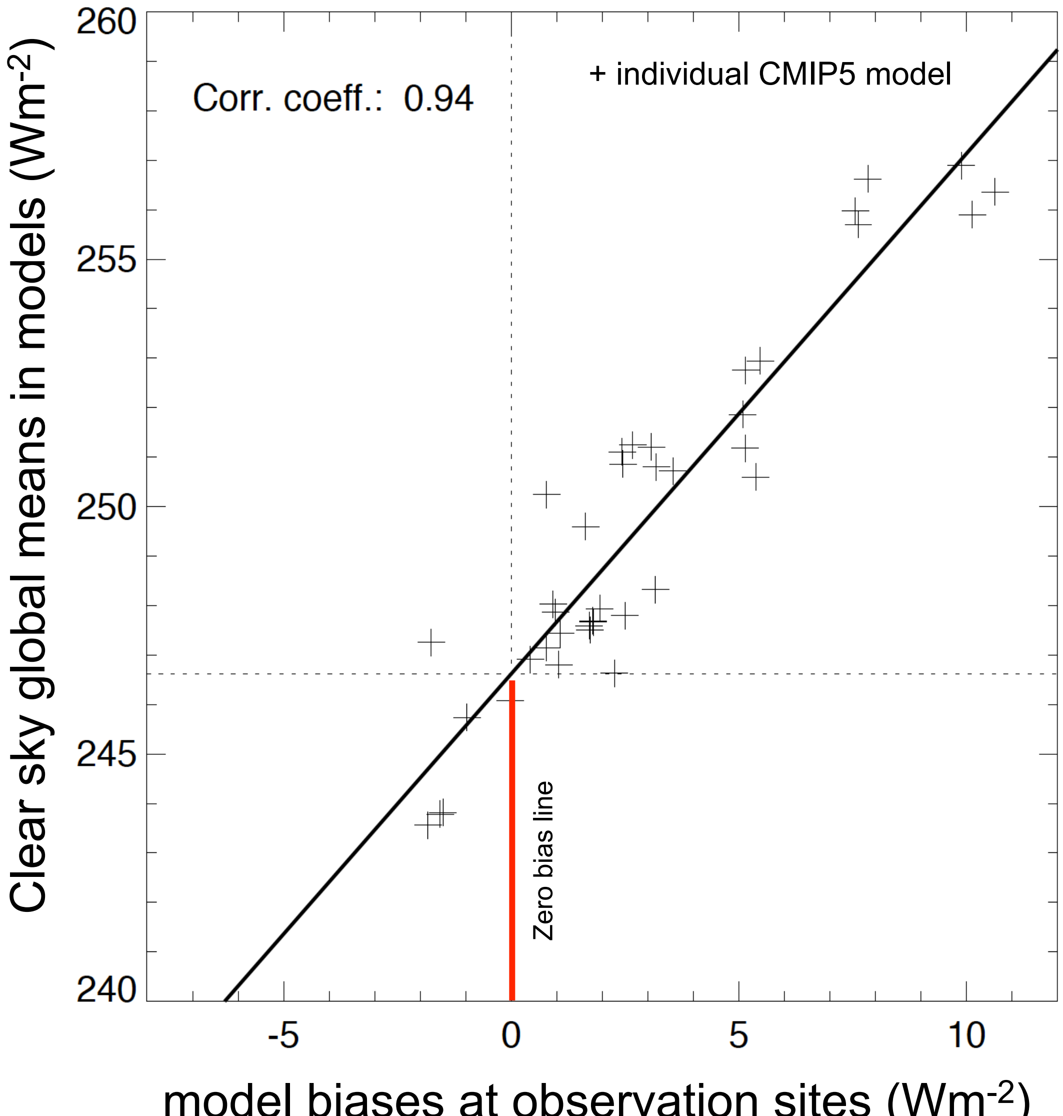
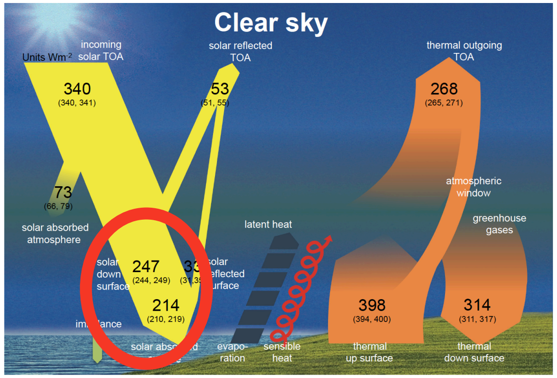
Best estimates for global mean clear sky fluxes

Surface SW down clear sky

GCM global means versus their biases averaged over BSRN sites





Best estimates for global mean clear sky fluxes

Surface SW down clear sky

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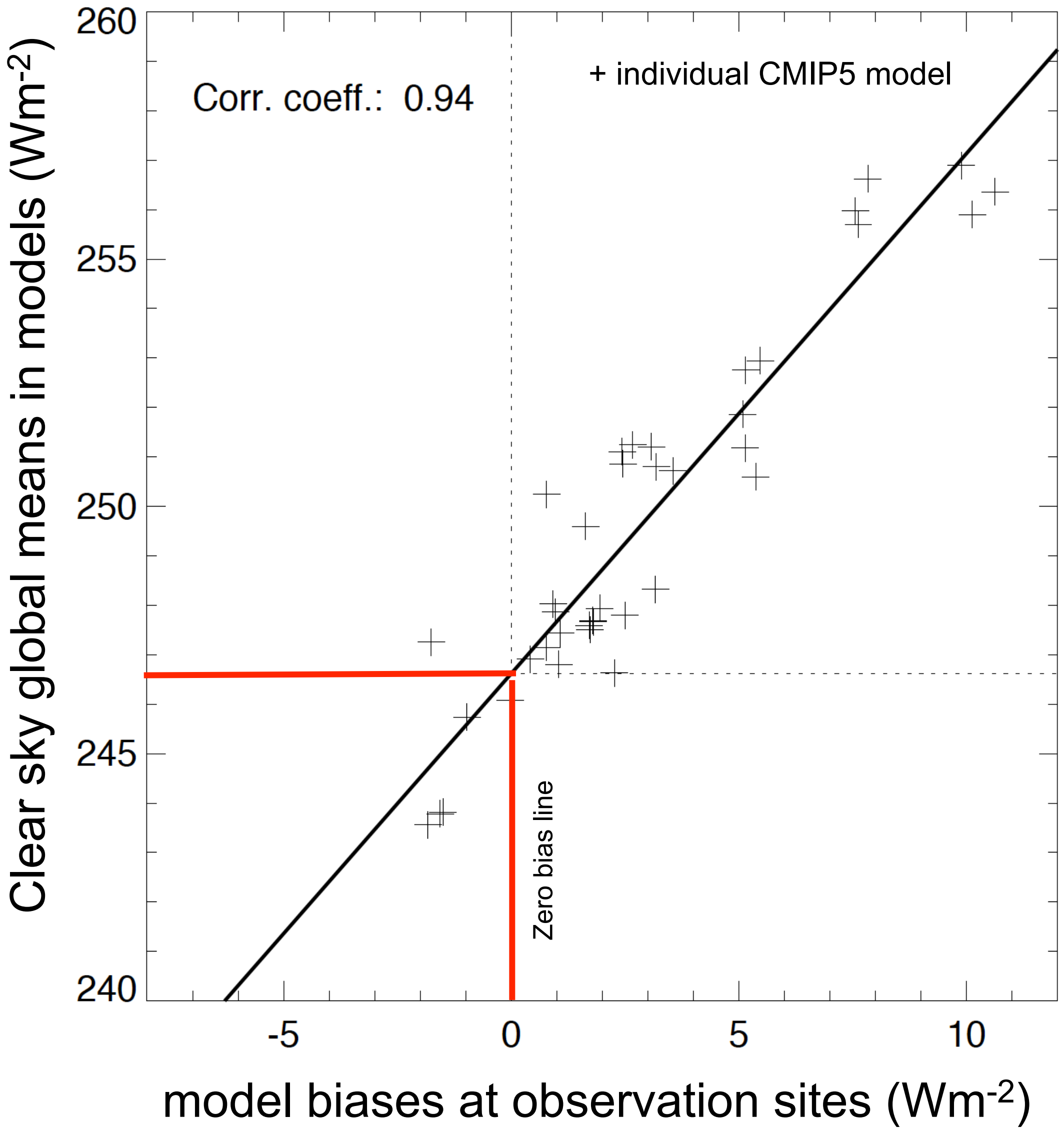
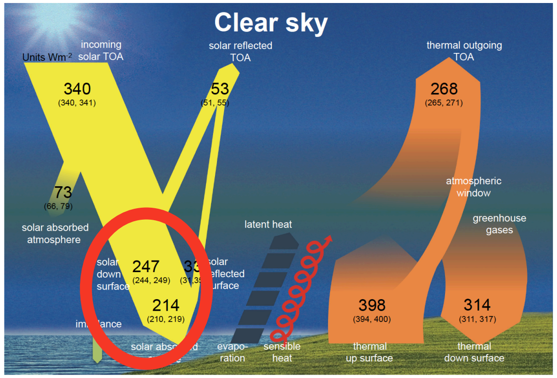


Best estimate surface SW down Clear sky:
247 Wm^{-2}



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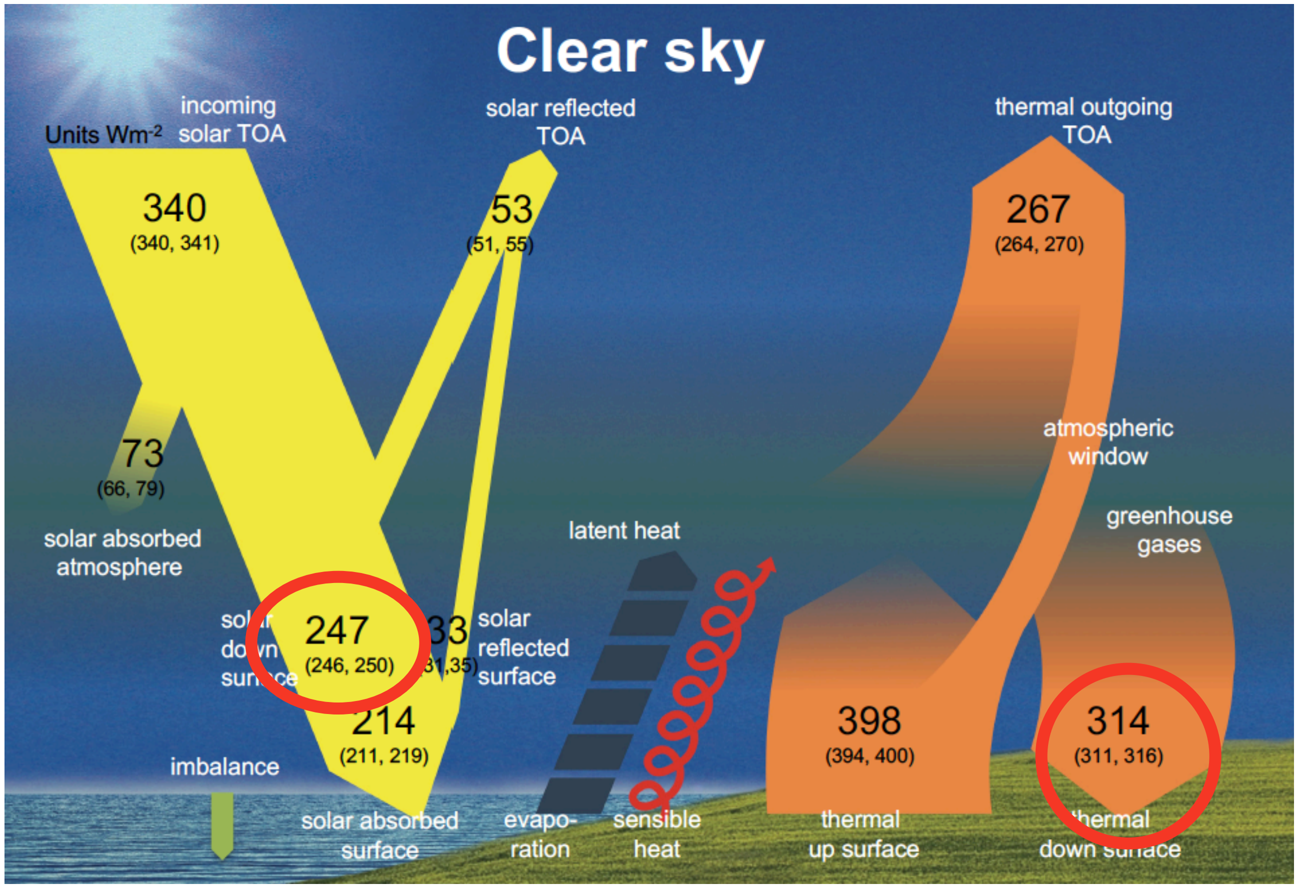
Earth Radiation Budget without clouds

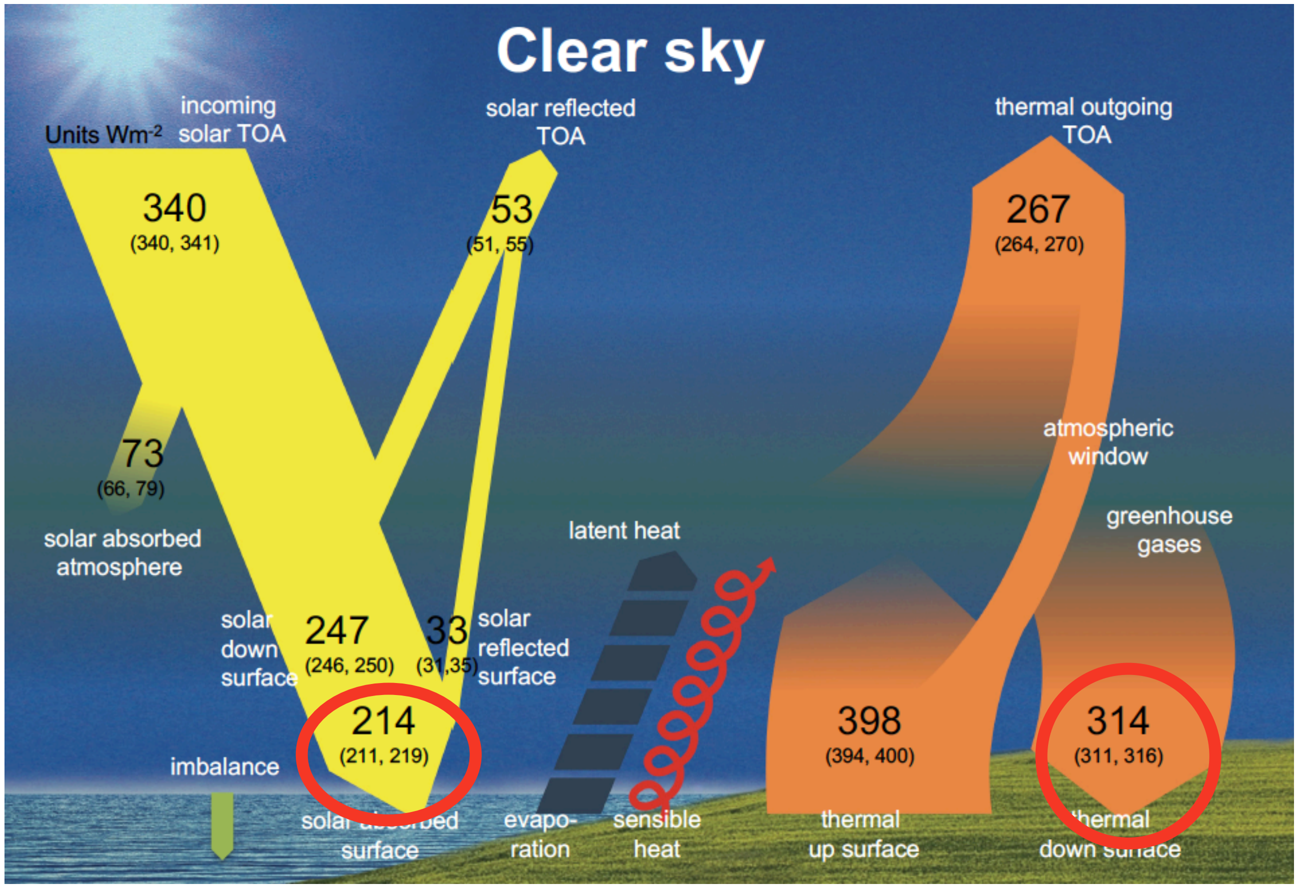


Global mean surface downward clear sky fluxes

BSRN observations + CMIP5

Wild et al. 2018, under review in Climate Dynamics

Earth Radiation Budget without clouds



Additional surface albedo estimate (0.13) to derive surface clear sky absorbed SW of 214 Wm^{-2}

Wild et al. 2018, under review in Climate Dynamics

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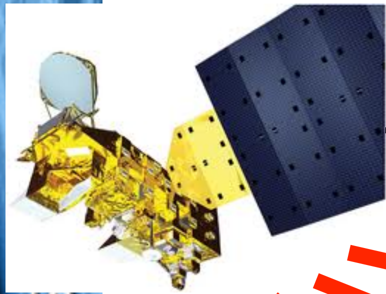
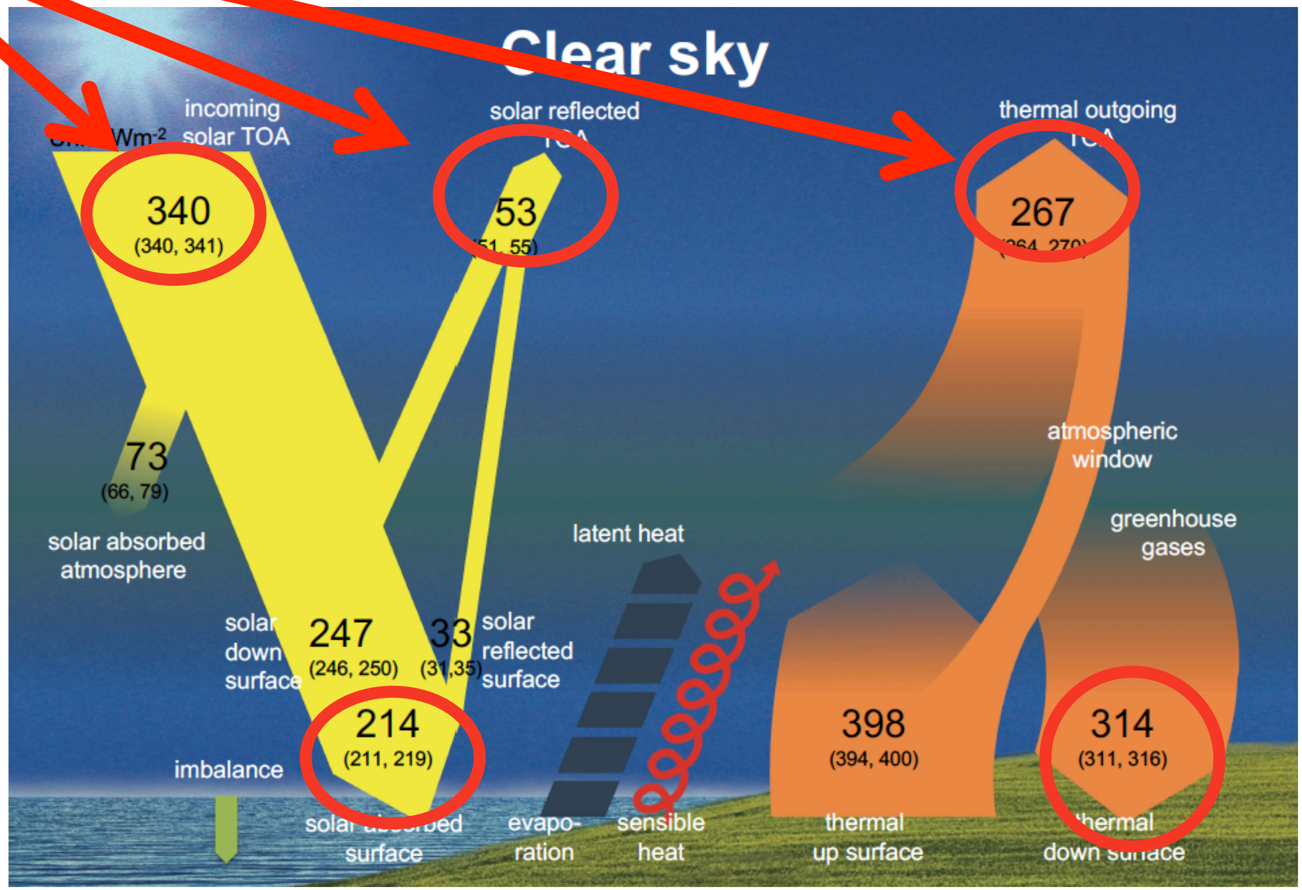


Earth Radiation Budget without clouds

Clear sky TOA fluxes from CERES EBAF



Wild et al. 2018, under review in Climate Dynamics

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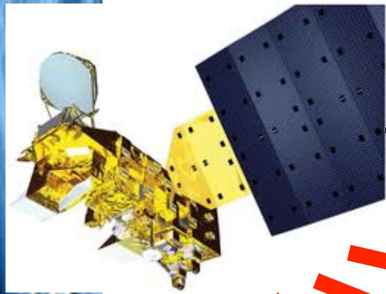
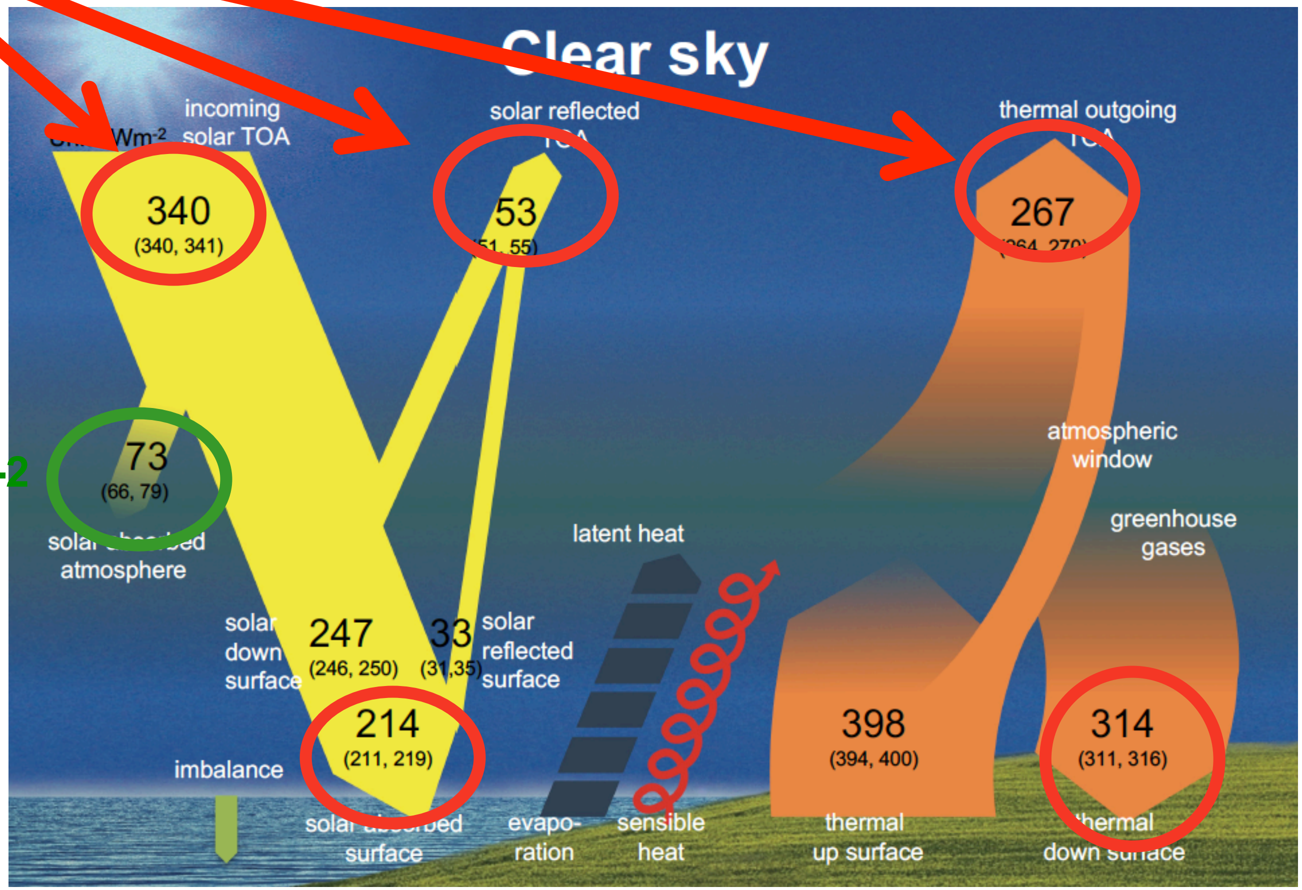


Clear sky TOA fluxes from CERES EBAF

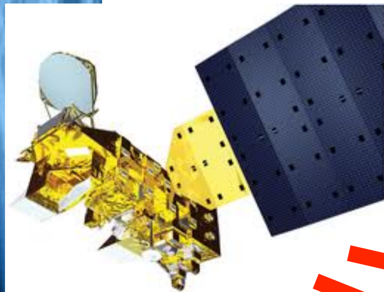
73 Wm^{-2}



Combining SW clear sky TOA and surface absorption to obtain atmospheric clear sky SW absorption of 73 Wm^{-2}

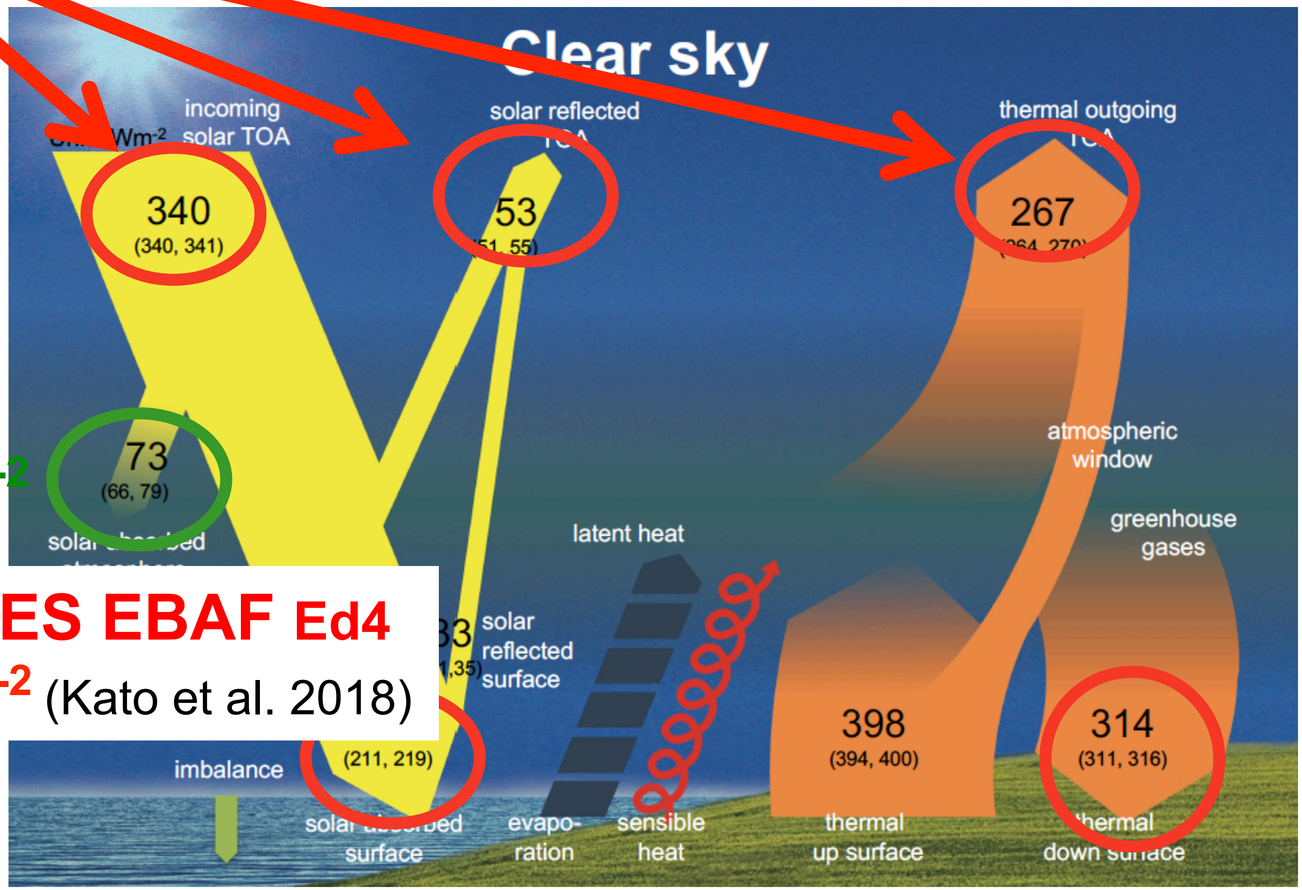
Wild et al. 2018, under review in Climate Dynamics

INSTITUTE FOR ATMOSPHERIC AND CLIMATE S



Earth Radiation Budget without clouds

Clear sky TOA fluxes from CERES EBAF



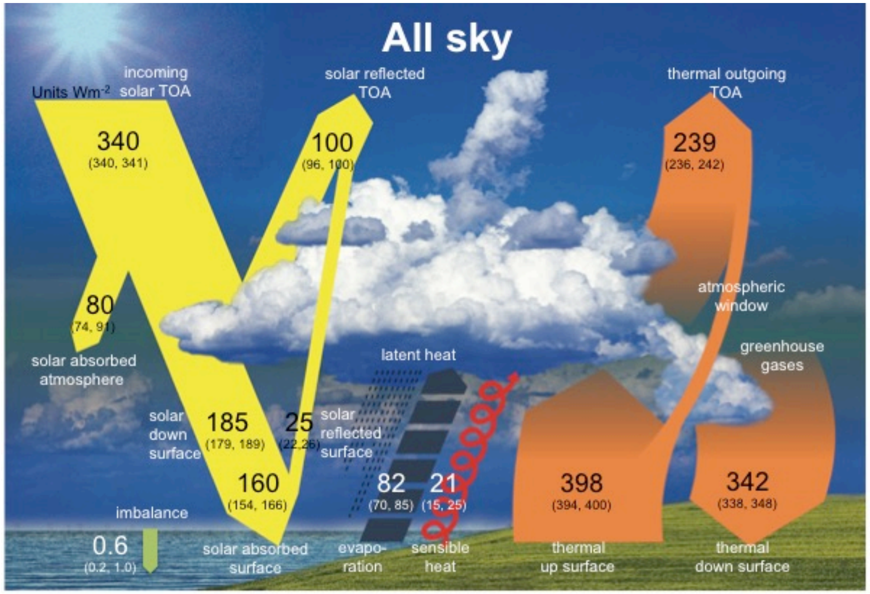
73 Wm^{-2}

cf. CERES EBAF Ed4
73 Wm^{-2} (Kato et al. 2018)

Combining SW clear sky TOA and surface absorption to obtain atmospheric clear sky SW absorption of 73 Wm^{-2}

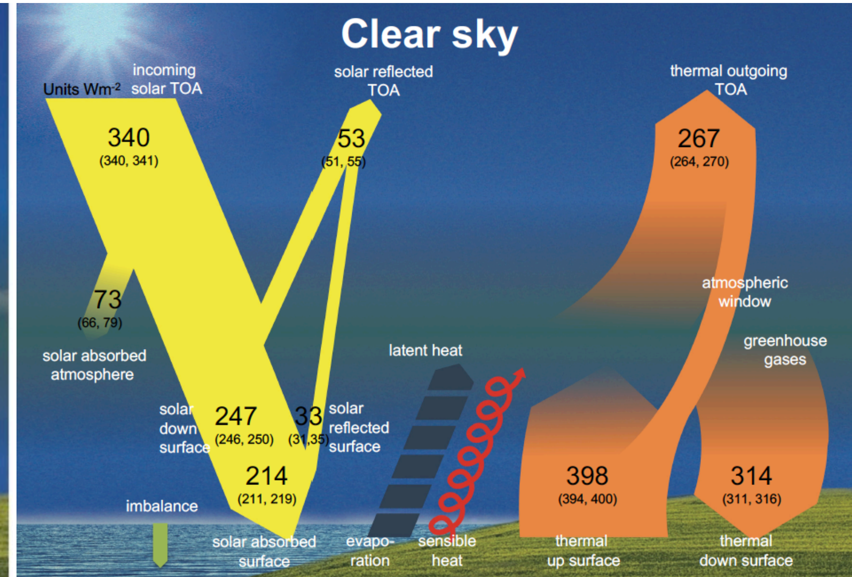
Global mean Cloud Radiative Effect (CRE)

All sky



Wild et al 2015 Clim. Dyn.

Clear sky



Present study

Units Wm^{-2}	SW CRE	LW CRE	Net CRE
TOA	-47	28	-19
Atmosphere	7	0	7
Surface	-54	28	-26
Surface CMIP5	-53	25	-28

Wild et al. 2018, under review in Climate Dynamics

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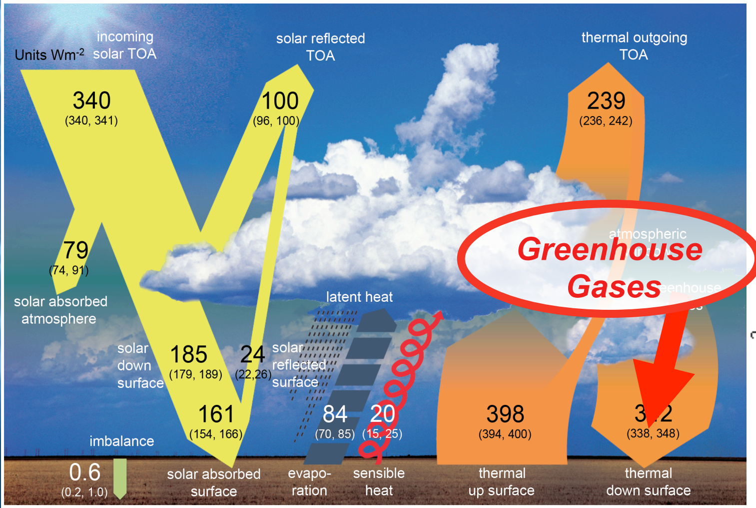
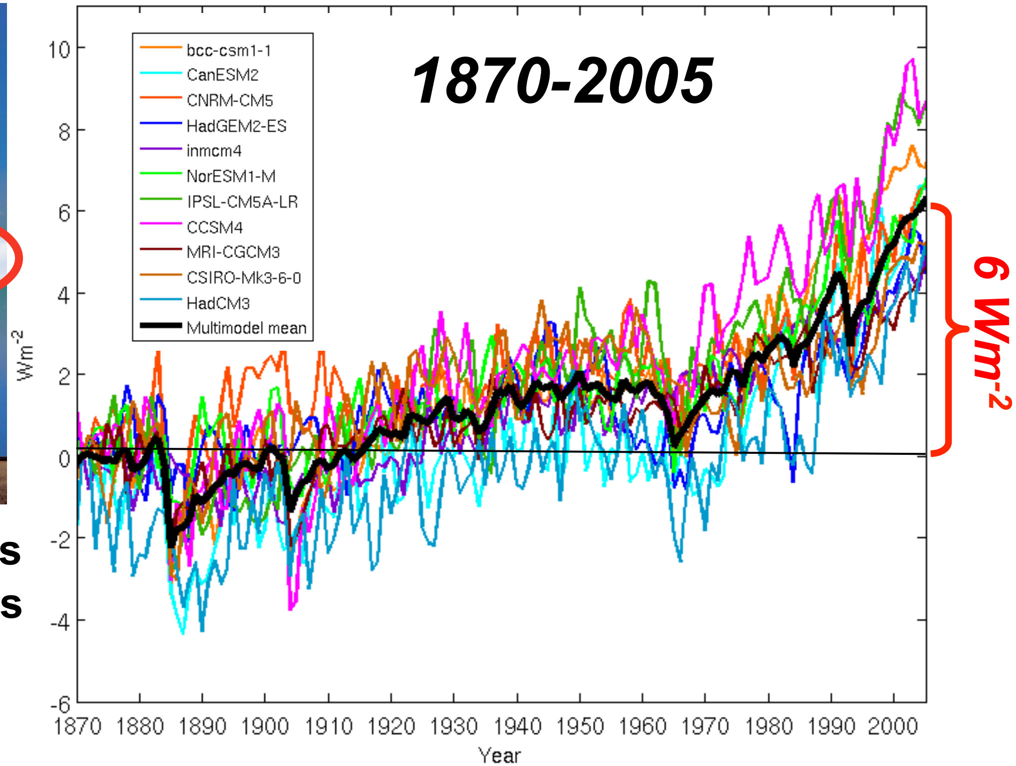
Temporal changes in surface radiative fluxes

Changes in downward longwave radiation



Downward longwave radiation in CMIP5 models

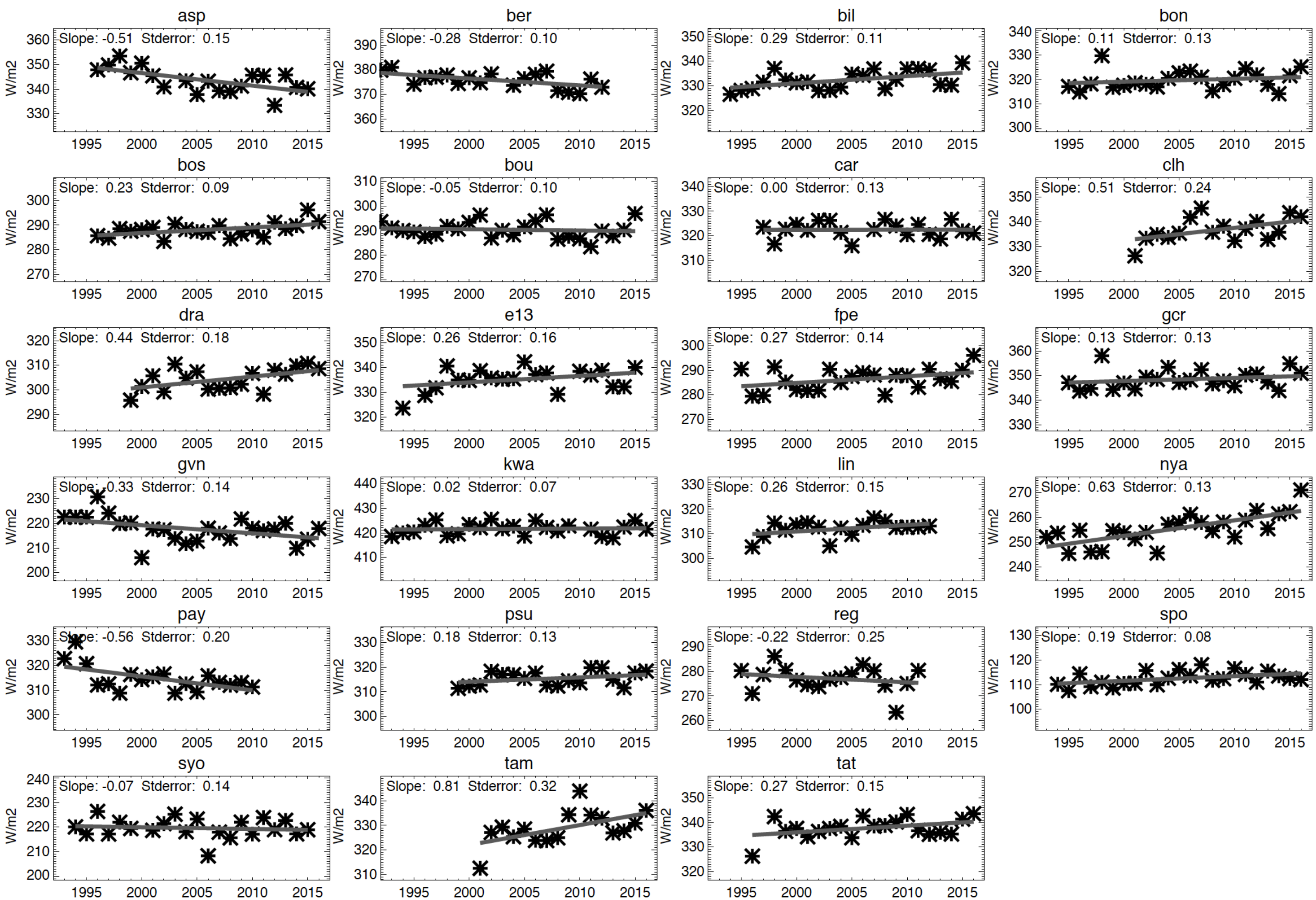


- **most directly affected by changes in atmospheric greenhouse gases**
- **expected to undergo largest change of all energy balance components in coming decades**
- **CMIP5 models suggest increase of 6 Wm^{-2} since 1870**
- **Only monitored since the initiation of BSRN early 1990s**

BSRN LW down trends: update to 2017

23 stations with min 15 years: totally 465 years, 16 (13) pos., 7 (4) neg.

Median change: 1.7 $Wm^{-2}decade^{-1}$



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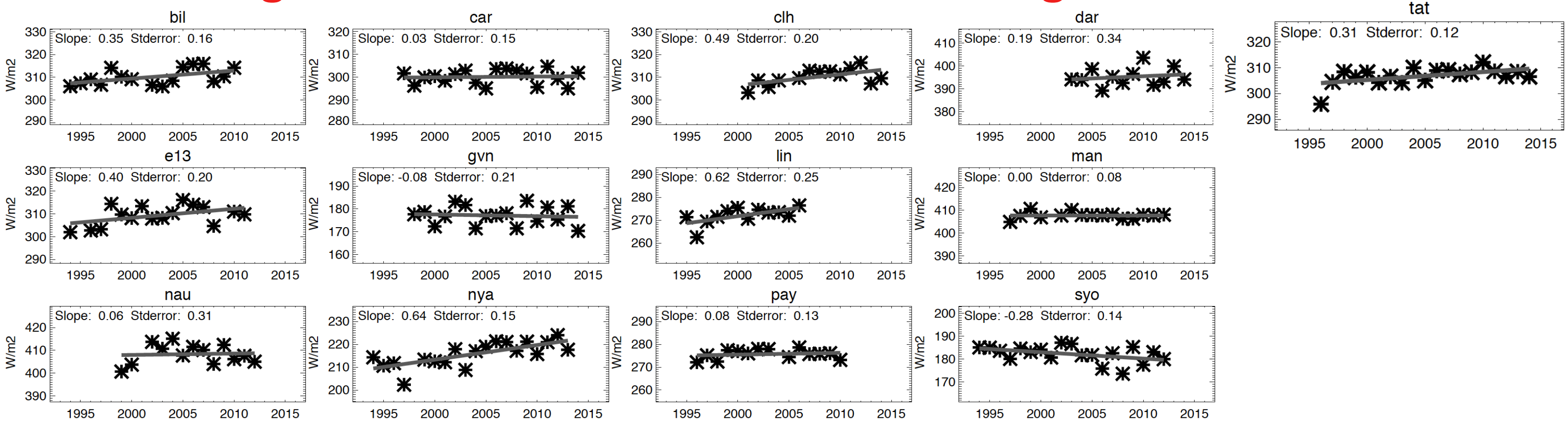
BSRN LW down clear sky vs. all sky trends

Clear-sky: 13 stations with min 12 years: totally 203 years, 11 (6) pos., 2 (1) neg.

Mean change: 2.1 $Wm^{-2}decade^{-1}$ Median change: 1.9 $Wm^{-2}decade^{-1}$



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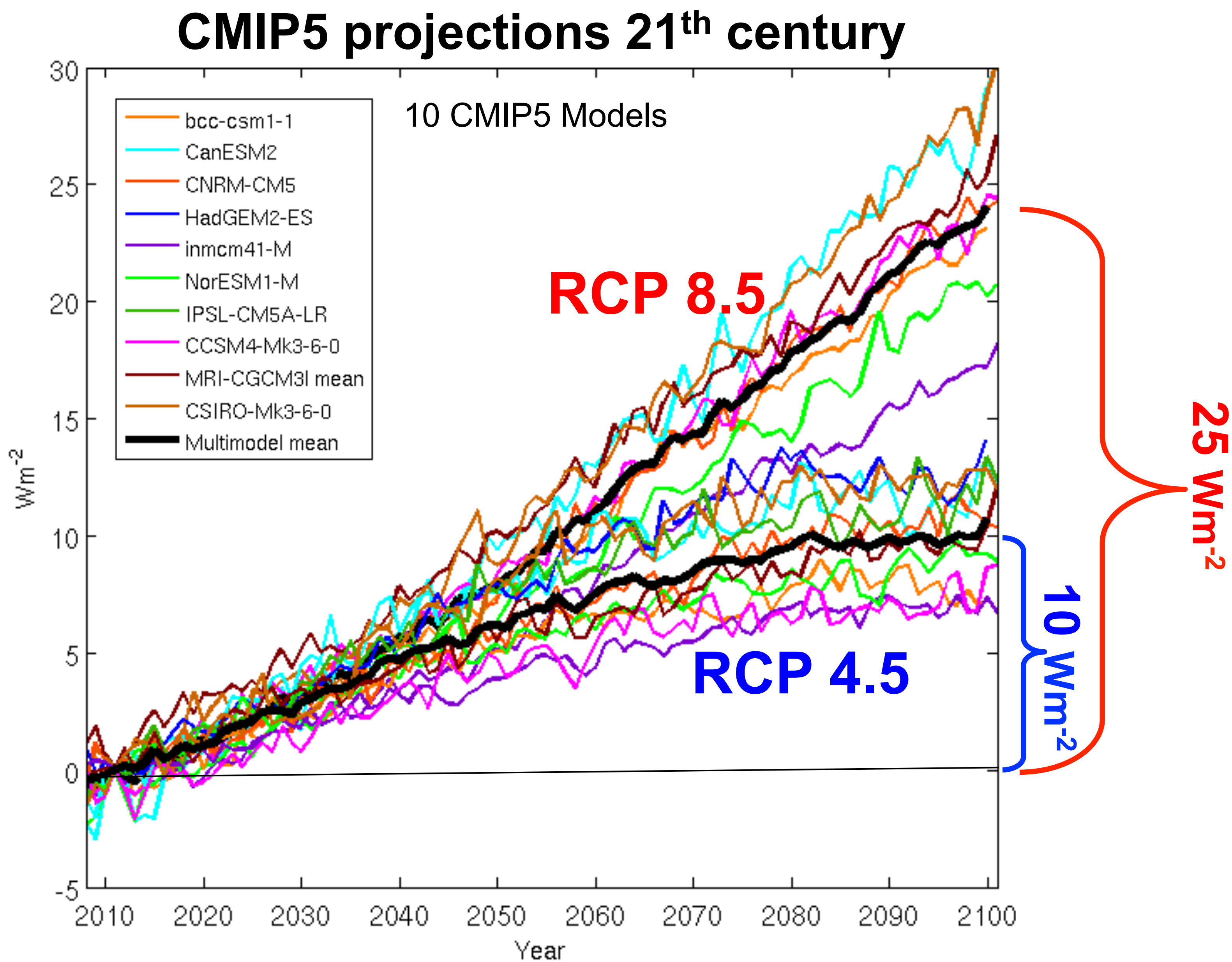
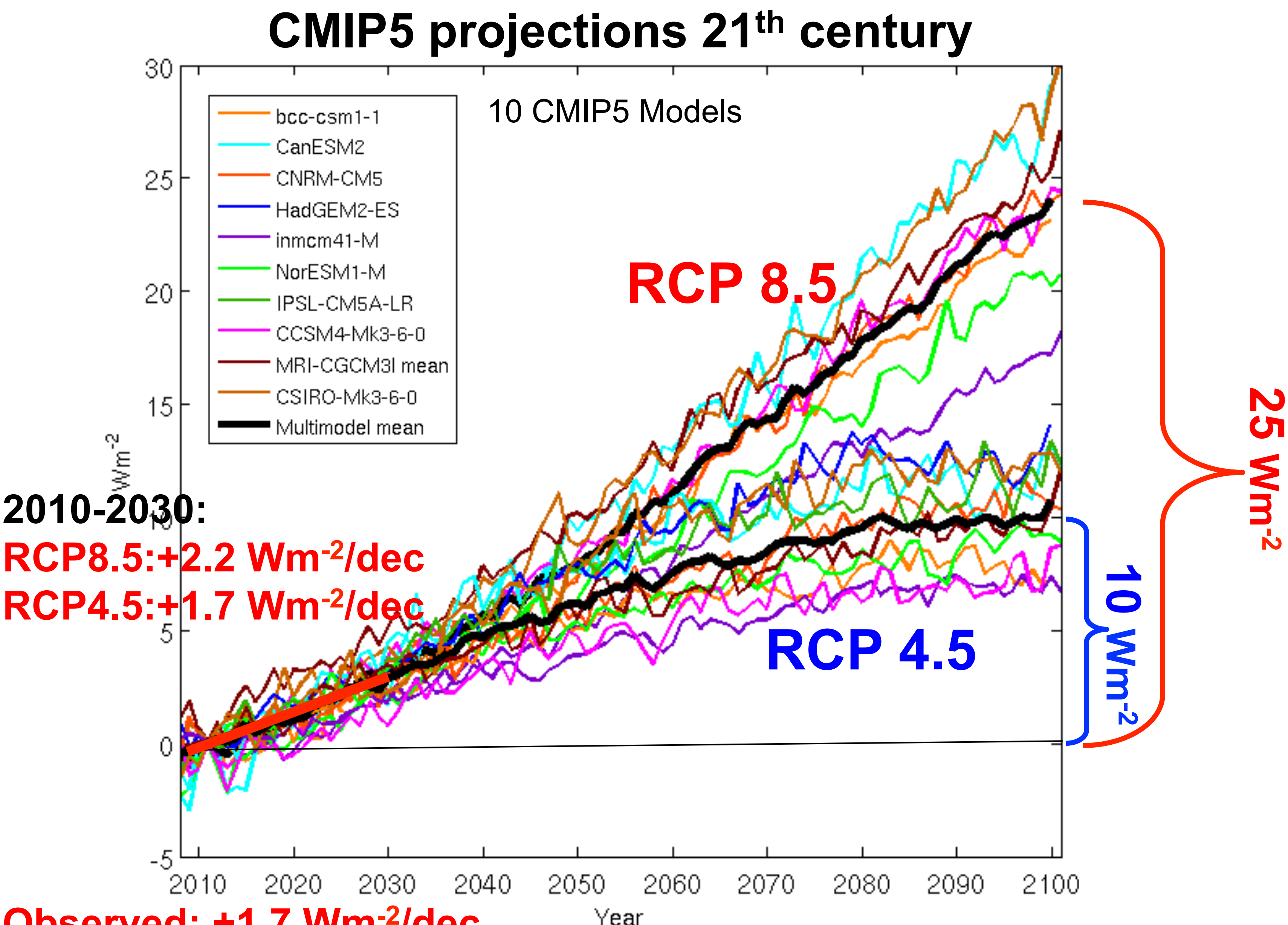
Future changes in downward longwave radiation



Future changes in downward longwave radiation



Observed: +1.7 Wm^{-2}/dec

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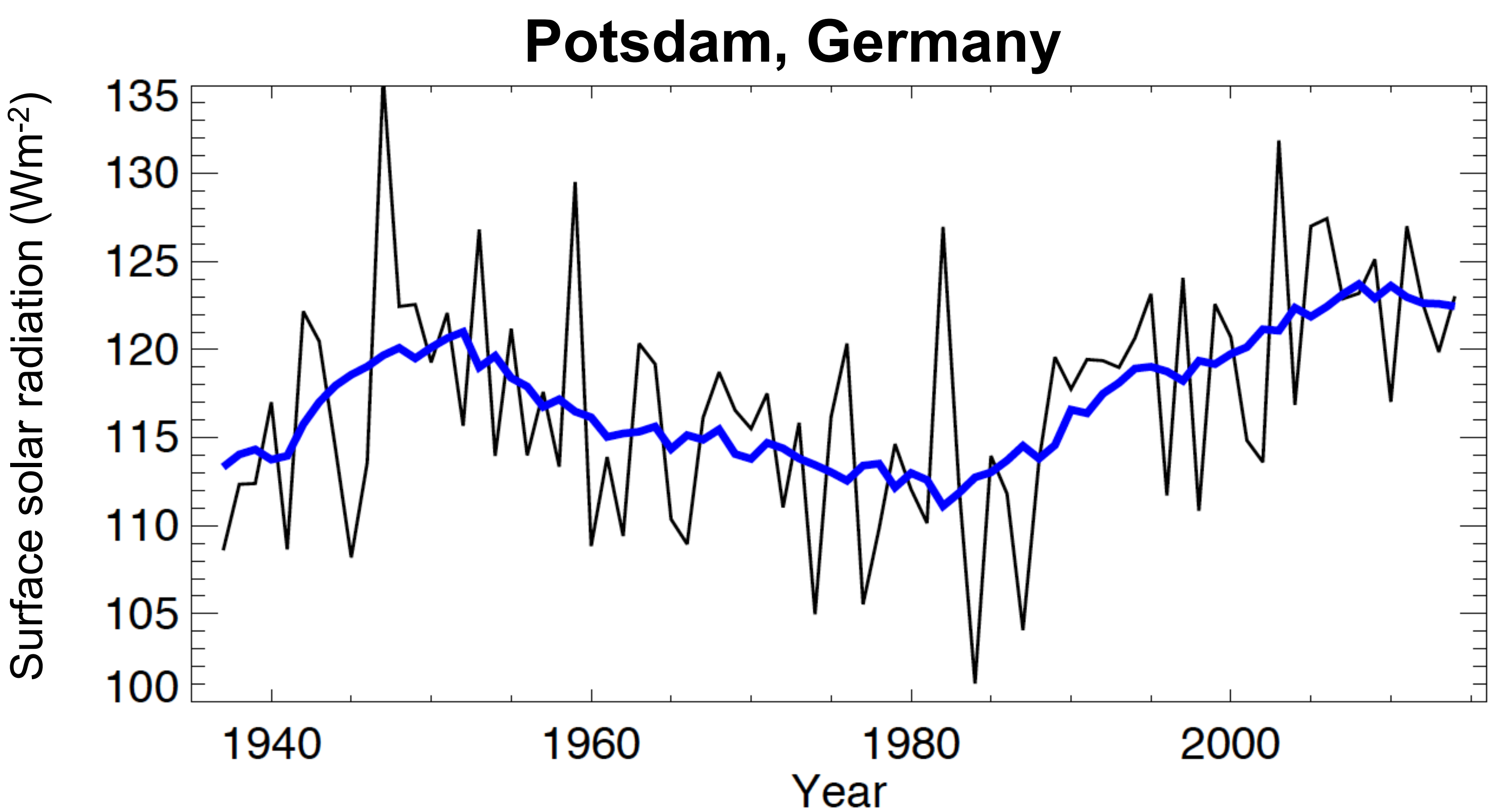
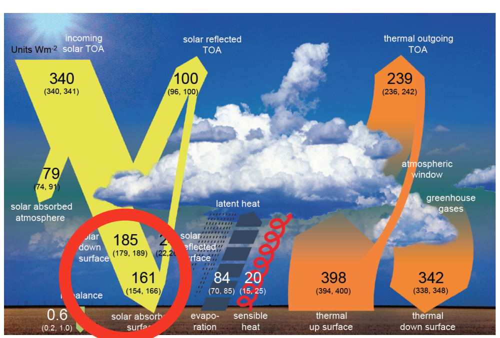
Decadal changes in surface solar radiation





Wild et al. 2005 *Science*
Wild 2016, *WIREs Clim Change*

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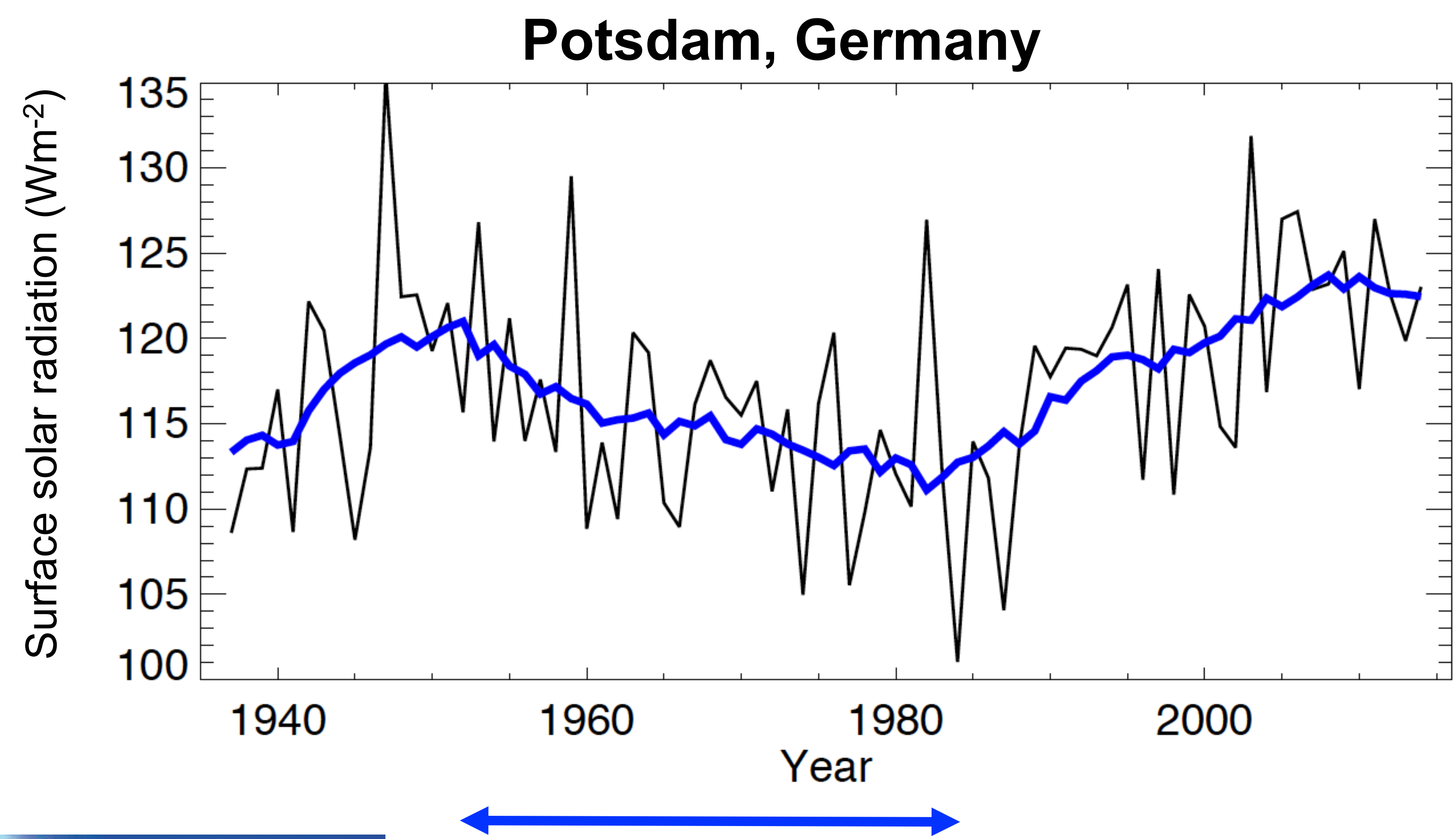
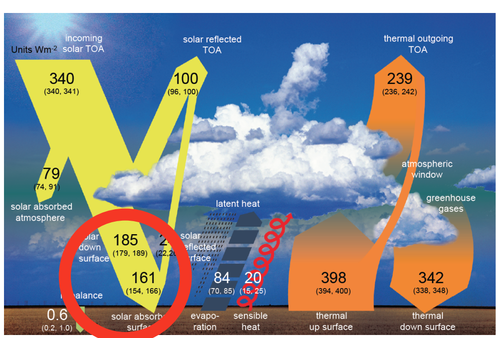
Decadal changes in surface solar radiation



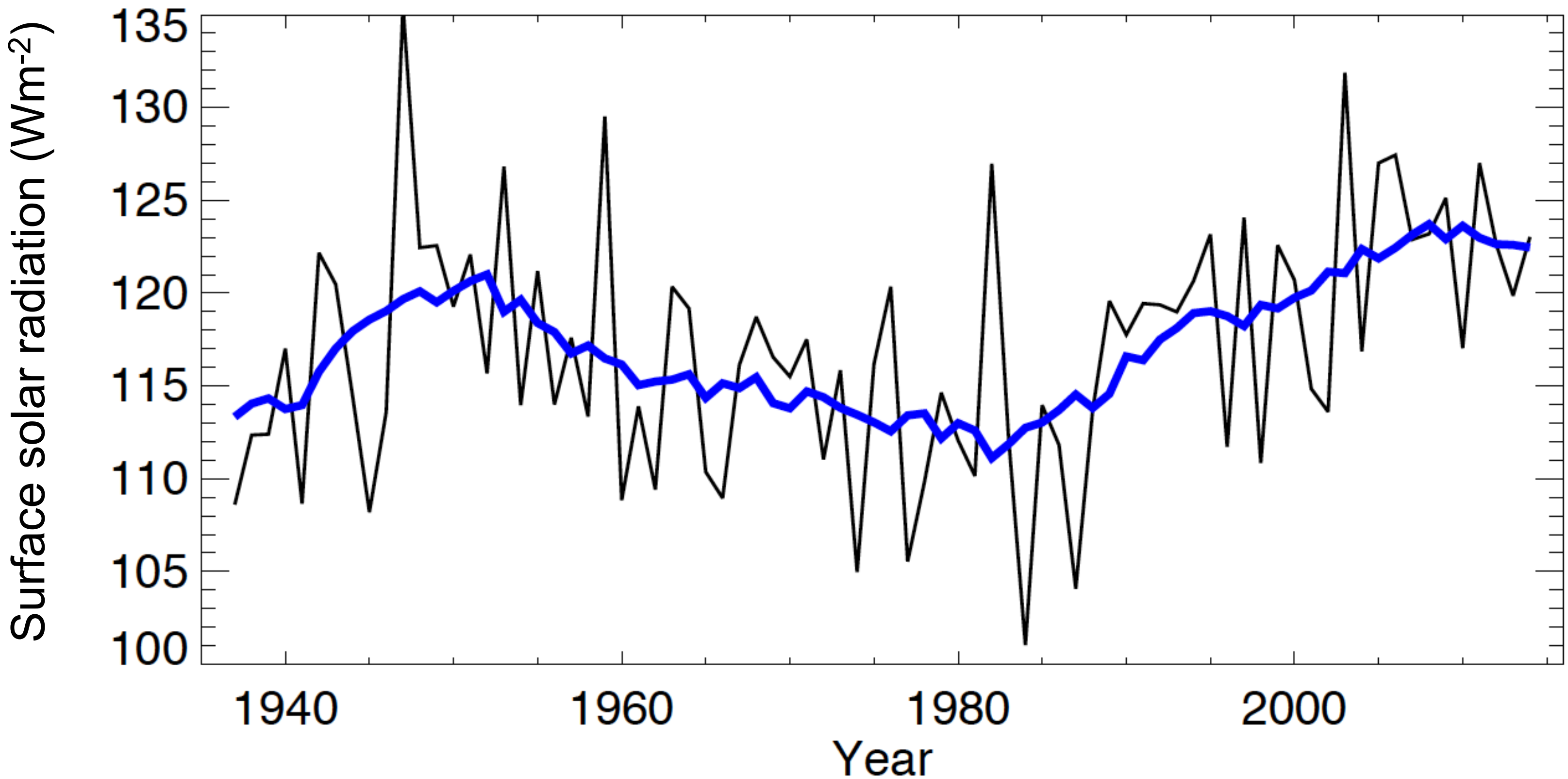
"dimming"



Wild et al. 2005 *Science*
Wild 2016, *WIREs Clim Change*

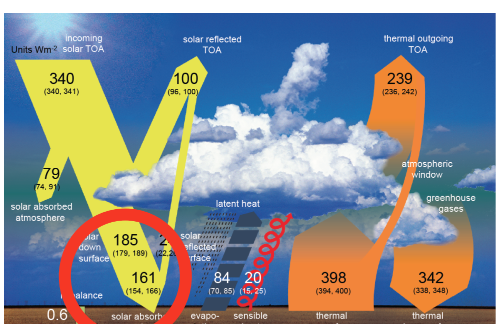
Decadal changes in surface solar radiation

Potsdam, Germany



"dimming"

"brightening"



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Decadal changes in surface solar radiation

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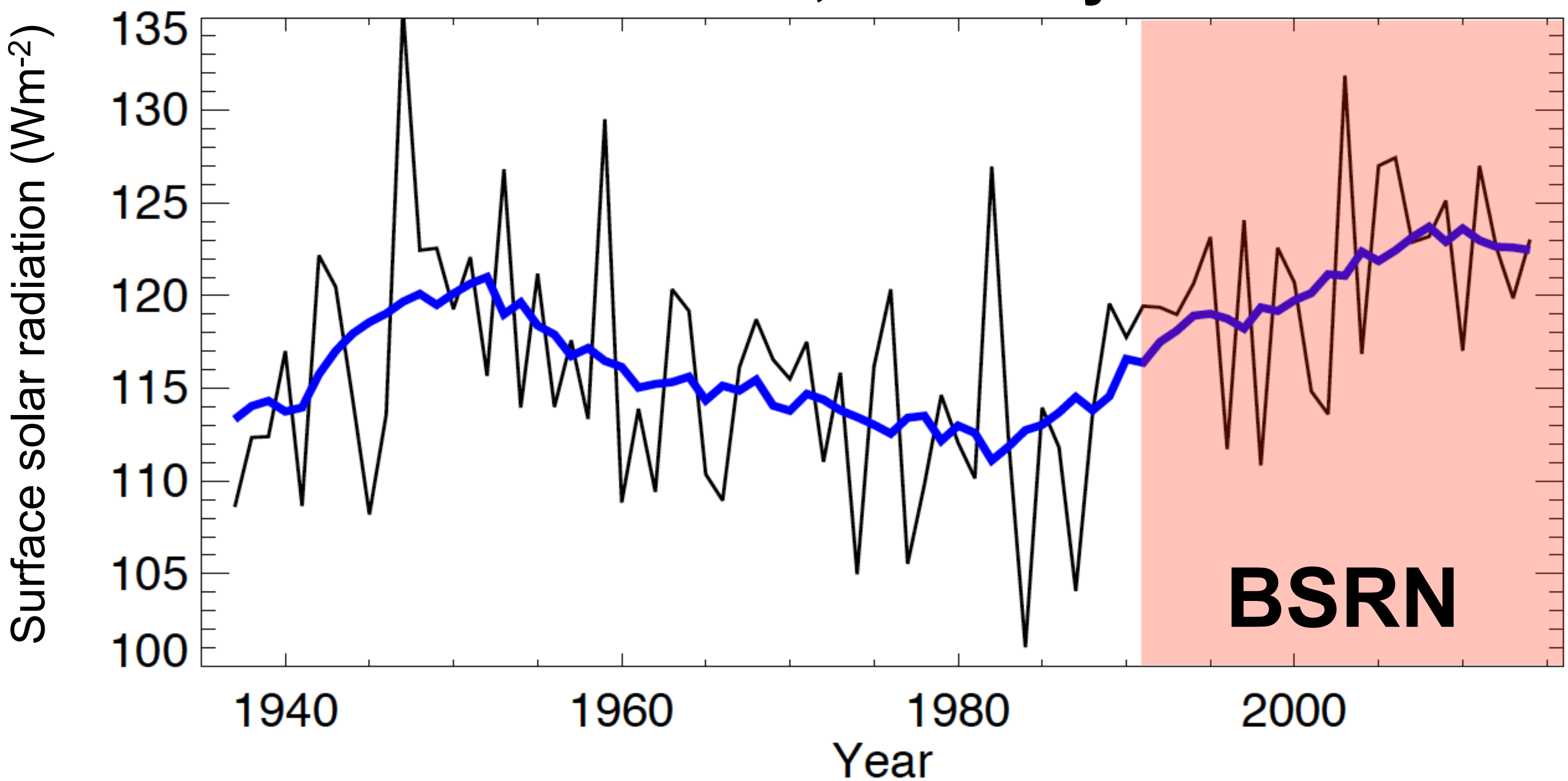
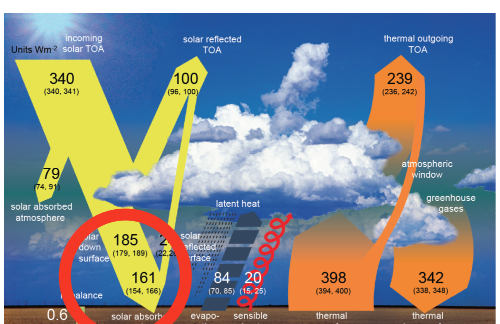


“dimming”

“brightening”



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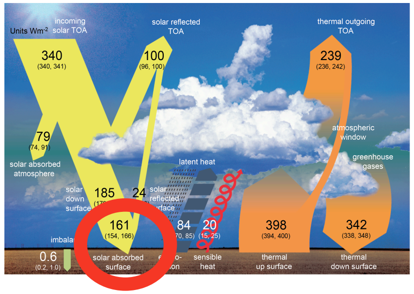
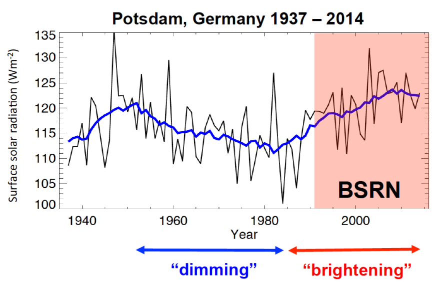
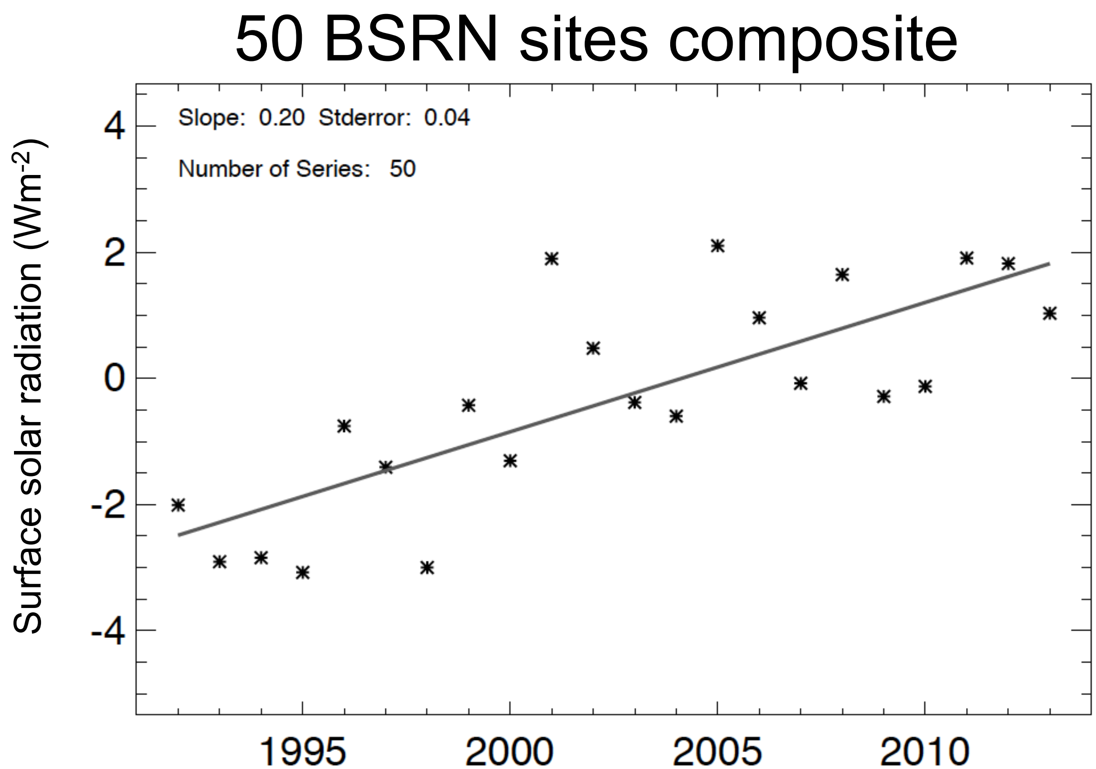
Decadal changes in surface solar radiation







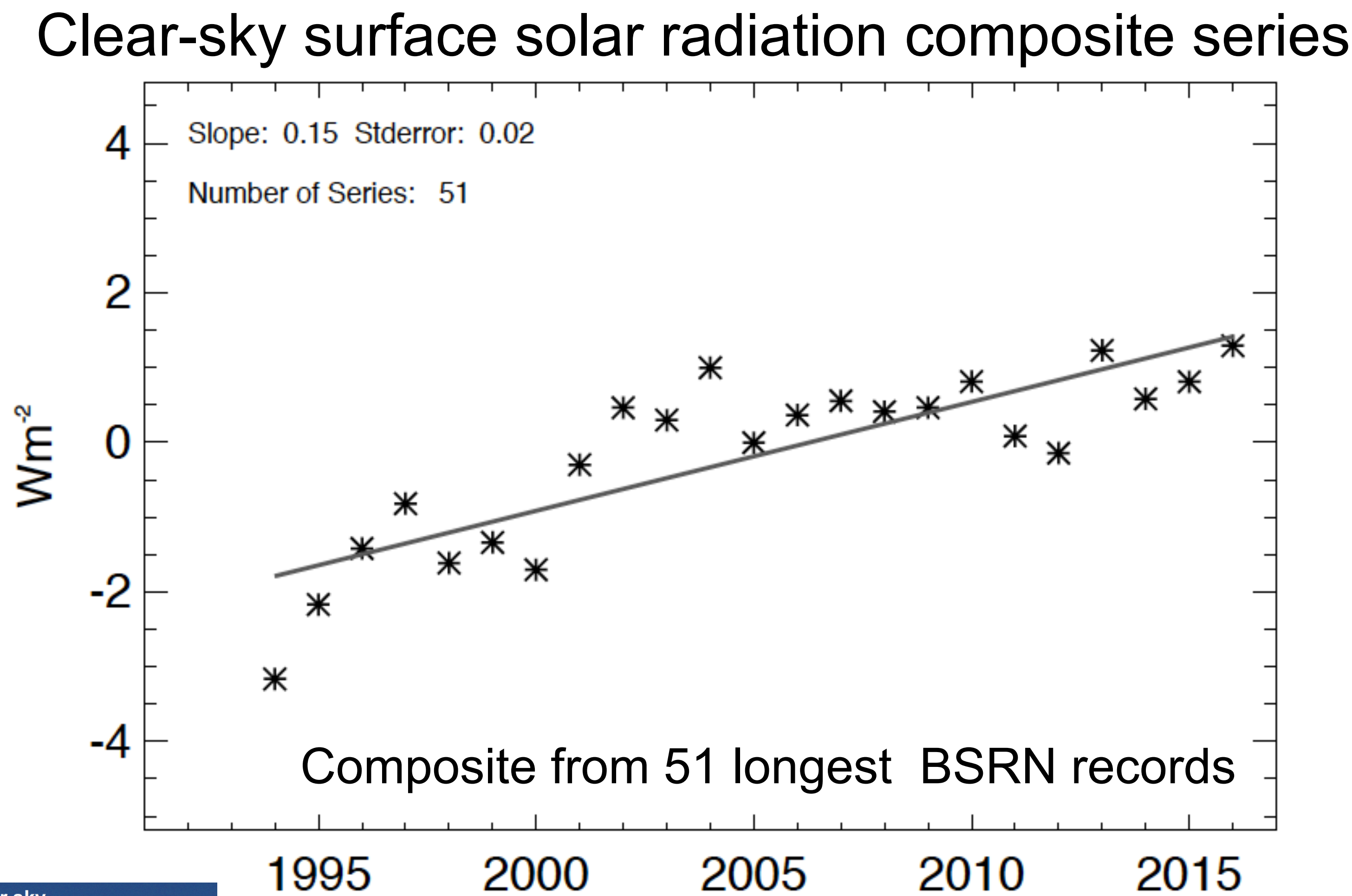
Observed changes at BSRN sites since early 1990s:

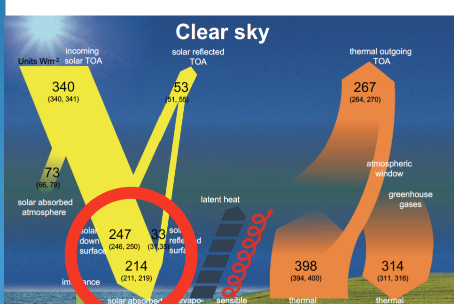
Average change all sites: +2 $Wm^{-2}dec^{-1}$

23 longest BSRN records (totally 353 years)

- ***20 stations (87%) with increase*** *in SW down (11 significant)*
- ***3 stations (13%) with decrease*** *in SW down (0 significant)*

Composite solar clear sky BSRN time series





=> Brightening under clear skies

Conclusions

- BSRN were crucial for the estimation of the surface components of the Global Energy Balance in the 5th IPCC Assessment Report (AR5)
- Clear-sky surface solar radiation flux climatologies can be inferred from minute data of the BSRN records.
- So far used for assessment of clear-sky fluxes in the CMIP5 global climate models and for the estimation of the global energy balance under cloud-free condition, as well as the global cloud radiative effects.
- Significant decadal changes observed in both downward longwave and shortwave BSRN records.
- BSRN records indicate an overall increase in downward LW radiation of 2 Wm^{-2} per decade under clear skies, in line with CMIP5 simulations and expectations from an increasing greenhouse effect
- BSRN records show an overall increase in surface solar radiation since the 1990s (“brightening”) with a recent leveling off, both under clear-sky and all-sky conditions.